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POTENTIAL EVALUATION OF THERMOCHEMICAL BIOMASS MIMOSA CAESALPINIIFOLIA BENTH FOR OPERATION IN A FIXED BED GASIFIER

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The unbridled growth of the industrial potential in the world, since the Industrial Revolution, caused a lot of environmental issues which started a race for sustainable technological development where the scientific community needs to find out sustainable ways of industrial production, and one of the ways can be the use of biomass to support the necessary demand. Gasification is an alternative to the use of biomass, and it is defined as the conversion of any solid fuel into an energy gas, by partial oxidation at high temperatures (800ºC – 1000ºC). The produced gas has many practical applications, like combustion in engines or turbines for power generation, in boilers and furnaces or as a source for the production of raw material to chemical synthesis. This project proposes a physico-chemical evaluation of the biomass Mimosa caesalpiniifolia Benth, known as wood of "Sabiá", to be used as fuel in the gasification process. This evaluation followed the standards NBR 8112 and ASTM E-870-82 to obtain the immediately analyses of the wood which gave the following parameters: moisture content, volatile content, ash content and fixed carbon content. To obtain the superior calorific power and lower calorific power it was used a calorimeter. The study presented a very positive data regarding the use of wood of sabiá as fuel for gasification.

Keywords: *gasification, sustainable, biomass.*

1. Introduction

Biomass is all the natural renewable resources which comes from organic material of vegetal or animal origin, with the main objective of energy production.

Since the energy rationing on 2001, the theme of the use of biomass to energy generation has been widely discussed in Brazil, mainly because it is one of the largest world producers of biomass. Goldemberg (2002) and Macedo (2002), for example, show the benefits of using energy arising from biomass in the reduction of emissions of CO_2, jobs generation, among others, but they also warn of the need to improve the energy conversion technologies for the appropriate utilization of this renewable resource.

Gasification is an alternative for the biomass utilization, it is defined as the conversion of any solid fuel in an energetic gas, by the partial oxidation at high temperatures (800 – 1000°C) (Sanchez, 2010). This conversion can be performed in various types of reactors, fixed bed or fluidized bed. The produced gas has many practical applications, since the combustion in engines or turbines to power generation and electrical energy, on irrigation bombs, on the direct generation of heat in burners and furnaces, or as a source for the production of raw materials for chemical syntheses.

This study aims to find alternative and sustainable ways of obtaining fuel produced from the gasification process. The organic material of plant origin chosen for the study is the sabiá wood, due to de abundance of this raw material in the state of Alagoas.

The *sabiá*, which has the scientific name: Mimosa caesalpiniifolia Benth, grows naturally on the Northeast of Brazil. This species has cespitose growth, i.e., from the same point in the plant base depart various stems or trunks and occurs preferentially in areas where the soil is deep and fertile. But, the plant has also shown good development in poorer soil sites. In these cases, it is cash crops. It is important to supply the plants with organic and/or chemical fertilization. This species stands out as one of the main sources of stakes for fences in the Northeast, especially in the state of Ceará. From the third to the fourth year can already provide poles for fences. The wood is also used for energy, with specific weight around 0.87 gcm^{-3} and approximately a 73% fixed carbon content.

This qualifies the species as a good option for the production of firewood and charcoal. (Ribaski, J. *et al*., 2003). The wood is heavy, hard, compact, very dense, shiny and smooth surface, high durability even when exposed to moisture.

Gonçalves, *et al*., 1999, rated physical and chemical properties of the wood of Mimosa caesalpiniifolia to indicate its potential use. They concluded that this species of wood is not indicated to cellulose production due to its low level of alpha cellulose (28.40%), high lignin content (32.40%) and high density weighted (0.80 gcm^{-3}). However, they confirmed that high level of lignin and the high density gives the wood potential for coal production. Considering that coal sold in bulk is sold by weight, and the wood of sabiá has a high density, which can be a great option for the coal production by little producers.

This project proposes a physico-chemical evaluation of the use of this biomass as fuel in the gasification process. This evaluation followed the standards NBR 8112 and ASTM E-870-82 to obtain the immediately analyses of the wood which gave the following parameters: moisture content, volatile content, ash content and fixed carbon content. To obtain the superior calorific power and lower calorific power it was used a calorimeter. To the ASTM standard it was made five tests and 3 tests following the standard NBR 8112. From the gasification process another parameter is essential to analyze the efficiency of the biomass as the fuel of process, the superior and lower calorific power. To obtain the superior calorific power and lower calorific power it was used a calorimeter. It was realized five tests to this parameter: three of them to the species "in natura" and two of them for the briquette of sabiá wood. The lower calorific power can be obtained by calculation in function of water mass and the superior calorific power.

2. Theoretical Foundation

To use a biomass as a fuel to the gasification process is necessary to know about some characteristics of the chosen biomass. Then it is necessary to make a characterization of the biomass to get data to assess the conditions of use this one as fuel. The characterization of the biomass should be based on their use and bring elements for understanding the determinants property, private properties for each application.

The immediate analysis provides the fractions by weight of moisture content, volatile, ashes and fixed carbon.

2.1 Moisture Content (MC)

The determination of the moisture content is to measure the amount of water present in a sample. The high moisture content in the biomass is a challenge because even after subjecting it to advanced mechanical extraction methods, still contains 60-80% of water. Incinerate as moist fuel reduces the net generated by the reactor, and to a moisture content of approximately 80% the heat generated becomes void because all the calorific power is consumed in the furnace to evaporated water. Therefore, you must have a biomass with low moisture content to use the calorific power only for the gasification process and not to be consumed in the reactor to evaporate the water.

2.3 Volatile Materials

The volatiles content is the part of fuel that separates in the form of gas when the fuel is subjected to a heating pattern. It is composed of fuel gas (such as methane, carbon monoxide, hydrogen) and non-combustible gases.

2.4 Ashes Content

Knowing the ash content is important as it may represent a significant portion of the total dry biomass, however for the same type of biomass the variation is relatively small. Besides the natural ash content of each fuel, we should worry about the ash content derived from the contamination material that happens during the process of harvesting and transportation. The reasons to worry about the ash content are: the ash doesn't burn and remains in the location process. Thus, it requires a proper withdrawal system; for being abrasive can damage (corrosion) parts of the equipment; in large quantities ash becomes an environmental liability, the disposal of this material is hard representing additional costs; ash is formed by inorganic oxide materials which can fuse to form incrustations inside of the reactor, damaging it.

2.5 Fixed Carbon

It is the fuel residue left after the volatile matter liberation and consists mainly in carbon, although, contains some volatile elements that were not released (O_2, H_2, N_2, S). Higher fixed carbon content takes longer biomass to be burned which increases it is calorific power. The Eq. (1) is the relation that determines the fixed carbon content:

(Carbon with ash mass (g) - Ash mass (g)) / (Dry sample mass (g)) (1)

2.6 Calorific Power

Calorific power is the amount of heat released by the complete burn of the fuel mass (or volume) unit, and having the reaction products cooled to the fuel temperature (18 or 25°C). The calorific power of a fuel gives its "energetic content", independently of the fact if it is or not a complete burn.

The fuel's calorific power is defined as the amount of internal energy contained in the fuel, therefore the bigger it is the calorific power, the more energy will it contain.

There are two types of calorific power: Higher heating value, Lower heating value.

Higher Heating Value (HHV): It is the amount of heat produced by 1 kg of fuel, when it is combusted with excess air and the exhaust gases are cooled in a way that the water vapor in them is condensed.

Lower Heating Value (LHV): It is the amount of heat produced by 1 kg of fuel, when it is combusted with excess air and the exhaust gases air cooled to the water boiling point, avoiding that the water contained in the combustion is condensed.

2.5.3 Mass of Water (m_{H2O})

The mass of the water is the amount of water in percentage of the total mass present in the studied biomass (humidity), being the same found in the vapor state for HHV calculation.

For the process of briquetting, some parameters of the raw material require attention. In order to be successful, the moisture of the material must be between 8 and 18%. Thus, a mass of water was stipulated in medium value, which was obtained through a balance, from the knowledge of the total moisture present in the biomass determined by immediate analysis of moisture content.

3. Methodology

3.1. ASTM E-780-82

It was determined the moisture content on a wet basis using a drying oven, porcelain crucibles all with cover, analytical balance AUY-220 BALANCE ANALYTICAL CAP.220GR SHIMADZU and desiccant.

The crucibles and the covers were placed for one hour in an oven at 110°C (104°C to 110°C), and were then placed in a desiccator for thirty minutes until it reached room temperature so that they could be weighed; the crucibles were weighed with the covers and noted the value given by the balance, continuing, filled up three quarters of crucibles with a sample of the biomass, capped and weighed, noting the value obtained.

Having the crucibles with the sample weighed, they were uncovered and both uncovered crucibles and their covers were placed in the oven for two hours at 110°C. After two hours the crucibles and covers were removed and now with the crucibles capped, they were placed in the desiccator for thirty minutes until it reached room temperature. The capped crucibles were weighed and the obtained value noted. The procedure of placing uncovered crucibles and their covers in the oven was repeated, however in a shorter period of time, for thirty minutes, and after in the desiccator for thirty minutes until it reached room temperature so that they could be weighed, the new obtained value was compared with the previous, if there was no important variation, it was noted, in case there was an important variation the procedure was repeated until this variation became negligible. When the procedure of moisture content determination in wet basis was over the capped samples were placed in the desiccator.

The dry samples obtained through the determination of moisture content kept in the desiccator were removed and placed in a muffle, on at a time for six minutes, where this muffle is heated up to 850°C, and only when this value of 850°C is reached that the samples are placed one at a time, waited until the muffle reached 100°C so that it could be opened and the samples removed, avoiding damages to the equipment. This procedure was performed for all the samples with biomass, which lasted about 1 hour. They were taken to the desiccator and waited until was reached room temperature, lasted about 1 hour. After, the samples were weighed and the value noted, and then they were placed in the desiccator for the analyzes continuation.

With the muffle cold, the samples that were kept in the desiccator are placed with the crucibles uncovered in the muffle which begins to be heated slowly until 750°C and was maintained at this temperature for two hours. The interval is given by the following procedure, while the muffle heats from 0°C to 500°C, its heating time is sixty minutes, with a programed heating speed of 8°C/min, after reaching the value of 500°C it is heating time remains the same of sixty minutes and its speed is amended to 4°C/min. With the wanted temperature reached, waited that the muffle reached 100°C so it could be opened and the sample removed, avoiding damages to the equipment, after, they were weighed by the balance and the obtained values noted.

The analyzes for Higher Heating Value (HHV) obtaining were performed through a C-200 calorimeter, analytical balance AUY-220 BALANCE ANALYTICAL CAP.220GR SHIMADZU, pure oxygen cylinder (99,95%). 5 analyzes were performed to obtain the SCP of the sabiá wood, with triplicate "in natura" and duplicate in briquettes.

"In natura": At first was collected and put in a crucible an amount of sabiá's wood of 0,9 to 1,1 g and taken to the analytical balance, where after it was weighed, began the preparation to determinate the Superior Calorific Power, which begins with the required adjustments in the metallic vase contained in the calorimeter bomb, it begins by opening the threaded vase with help of an appropriate tool, after it is opened and the equipment side found inside the vase inverted, connects up a cotton thread in the conducting wire, five (5) ml of distilled water are placed inside of the vase, with that the crucible with wood of sabiá was embedded in the handle, where occurs the combustion reaction, always putting in contact the biomass with the cotton thread. The vase is capped, pressurized in approximately 30 bar for thirty seconds and after pressurization another white cover is embedded on top of the vase. With the vase properly capped, it is placed inside of the calorimeter bomb. 2 (two) l of water are used to fill the tank. The calorimeter bomb was closed and the readout happens in approximately seventeen minutes. With the ending of this seventeen minutes, the value is found on the equipment display and its unit is in (J/g), with that the calorimeter is opened, the vase removed from inside the calorimeter bomb and on following uncovered. To open the vase depressurized it for approximately fifteen seconds and the crucible removed, where was possible to confirm the burn.

The analyzes obtaining, now in a briquette, were performed using the same procedure that was used for the biomass "in natura".

The results for Lower Heating Value (LHV) in "in natura" and in briquette were obtained through the already know values of Sabiá's wood and latent heat of water condensation, as the Eq. (2):

$$LHV=HHV - m_{H20} \, x \, h_{lv} \quad (2)$$

h_{lv}- latent heat of water condensation : 2,257.20 J/g
m_{H2O}- mass of water, in g.

3.2 NBR 8112

To obtain the moisture content, an oven is heated up to a temperature of 105 ° C and maintained at this temperature for 15 minutes to eliminate contaminants. After this procedure, were introduced mini briquettes made previously through a hydraulic press - each with 1 g weight - in crucibles and placed in the same oven at 105 ° C, where they remained for 30 minutes. Then, the crucibles were taken to the desiccator, where they remained for 30 minutes until they reached thermal equilibrium with the environment. Once reached, the crucibles were weighed again. This process was repeated until there were found mass values given for each crucible (an average time of 2 hours was assumed). Since no variation in weight of the samples, it was possible to obtain the final weight of the sample. Finished the procedure for determining the moisture content, the samples were placed in desiccator for continuity analysis. The Eq. (3) is used to determinate the moisture content by this method:

$$MC = [(m_0-m_1)/m_0]*100 \quad (3)$$

MC is the moisture content, in %;
m_0 – inicial mass of the sample, in g;
m_1 – final mass of the sample, in g.

It was removed the samples contained in the desiccant, i.e., free of moisture, and put them in a muffle furnace which was preheated to 700 ° C (± 10) and the crucibles were maintained the same until the material completely burned (approximate time 2 hours). The furnace was turned off and waited that the same reach 100 ° C for opening and removing the sample, thus avoiding damage to the equipment and less risk of accidents. The material was removed from the furnace, it took up to a desiccator and held for about 1 hour to obtain the thermal equilibrium with the environment. After this time, the samples were weighed and it was possible to determine the final mass of the biomass contained in the pot residue. The Eq. (4) is used to determinate the ashes content by this method:

$$AC = [m_1/m]*100 \quad (4)$$

AC is the ashes content, in %;
m_1 – sample residues mass, in g;
m – initial mass of the sample, in g.

The dried samples were took from the desiccant and placed on the door of the muffle (which was previously heated to 900°C ± 10°C) for 3 minutes, after inserted inside the muffle for another 7 minutes, which amounted to a 10 minute procedure. The muffle was turned off and waited it reach a temperature of 100°C to remove the sample. This was put on the desiccator for 2 hours to reach thermal equilibrium with the environment. After this, the samples were weighed and with the Eq. (5) it was possible obtain the volatile content:

$$VC = [(m_2-m_3)/m_2]*100 \quad (5)$$

VC is the volatile content, in %;
m_2 – initial mass of the crucible + sample residue mass, in g;
m_3 – final mass of the crucible + sample residue mass, in g;

Equation (6) can be used to obtain the fixed carbon content:

$$FC = 100 – (AC + VC) \quad (6)$$

FC is the fixed carbon content, in %;
AC is the Ashes content;
VC is the volatile content.

The superior and lower calorific power was obtained with the same method explained at the ASTM E-780-82 standard. This parameter is not associated to any standard rule. It is obtained in a specific equipment called calorimeter.

4. Results

Following the standard ASTM E-780-82 it was possible obtain the data shown on the Tab. (1). This data refers to the initial parameters what is necessary to obtain the complete immediate analysis:

Table 1. Experimental results by the standard ASTM E-870-82 for *sabiá's wood*.

Data	1	2	3	4	5
	Weight of the crucible (g)	Mass of wet sample and the crucible (g)	Mass of the dry sample and the crucible (g)	Carbon mass and the crucible (g)	Ash mass and the crucible (g)
1	16.48	17.47	17.29	16.57	16.50
2	17.45	18.45	18.27	17.53	17.46
3	20.35	21.35	21.17	20.40	20.35
4	20.47	21.44	21.26	20.53	20.47
5	19.82	20.81	20.63	19.87	19.83
Average	18.91	19.90	29.73	18.98	18.92

With the data presented in Tab. 1 it was possible, following the methodology of the standard ASTM E-870-82, obtain the essential data for the study, that is showed on the Tab. 2:

Table 2. Experimental results from the evaluate of sabiá's wood by the standard ASTM E-780-82.

Data	6	7	8	9	10	11	12	13	14
	Mass of wet sample (g)	Mass of dry sample (g)	Carbon mass and ash mass (g)	Ash mass (g)	Humidity (%)	Carbon (%)	Volatily (%)	Ashes (%)	Total (%)
	(2-1)[(1)]	(3-1)[(1)]	(4-1)[(1)]	(5-1)[(1)]	(6-7)/6	(8-9)/7	(7-8)/7	(9/7)	
1	0.998	0.818	0.096	0.016	18.00	9.82	88.25	1.93	100
2	1.001	0.824	0.079	0.013	17.70	7.98	90.39	1.62	100
3	0.996	0.820	0.047	0.004	17.70	5.21	94.29	0.50	100
4	0.970	0.788	0.058	0.003	18.75	7.05	92.59	0.36	100
5	0.989	0.810	0.052	0.007	18.10	5.48	93.59	0.93	100
Average	0.991	0.812	0.066	0.009	18.10	7.10	91.83	1.07	100

(1) Data from the Tab. 1

For the NBR 8112 standard, were obtained the data contained in Tab. (3)

Table 3. Data for the test following the standard NBR 8112.

Sample	Crucible mass (g)	Crucible and briquette mass (g)	Briquette mass (g)	Crucible and wet briquette mass (g)	Wet briquette mass (g)	Ashes and crucibles mass (g)	Volatile mass (g)
1	11.89	12.87	0.98	12.71	0.83	11.89	11.59
2	10.99	12.48	0.99	12.33	0.84	11.01	10.72
3	10.53	12.98	0.98	12.82	0.84	10.54	12.10
Average	11.25	12.24	0.99	12.10	0.84	11.14	11.46

With these data, it was possible find the parameters of the characterization from the sabiá's wood, which is showed in Tab. (4):

Table 4. Parameters of the characterization of the sabiá's wood following the standard NBR 8112.

Sample	Humidity (%)	Ashes (%)	Volatile (%)	Fixed Carbon (%)
1	15.97	1.38	88.59	10.03%
2	15.33	1.42	86.82	11.76%
3	15.83	1.45	87.20	11.35%
Average	15.74%	1.42%	87.54%	11.04%

To concluding the evaluation, it was obtained the higher and lower heating value how is showed on the Tab. (5), when a mass of water was stipulated for 15,74% obtained with the standard NBR 8112:

Table 5. Values of superior and lower calorific power for sabiá's wood in species "in natura" and briquettes.

	Crucible mass (g)	Sample mass (g)	m_{H2O} (g)	HHV (J/g)	LHV (J/g)
"In Natura"	10.10	1.04	0.164	16278	15908
	10.52	1.04	0.164	16449	16079
	10.19	1.04	0.164	16523	16154
Briquette	10.19	0.92	0.145	17167	16840
	10.51	0.91	0.143	17246	16923

These data show a significant amount of calorific value. The petroleum coke, which is used in ceramics and steel mills, has a calorific value of up to 36,000J/g (Petrobras, 2012), i.e., the sabiá's wood reaches 50% of this value. When it is in form of briquette its HHV is a more than 'in nature' So, it is clear that this biomass can be used as a auxiliary fuel or as fuel in a gasification process, with the advantage of being a natural raw material, with low cost and less polluting source of energy.

5. Conclusion

The two evaluations from the sabiá's wood gave a similar result about all the parameters of the immediate analysis. The both studies was conducted with different humidity content, what cause a difference in the values data obtained since a sample with higher humidity than another has a volatile content higher than the other, for example.

The evaluations for the standard ASTM E-780-82 were realized with the sabiá's wood "in natura" while the evaluations for the standard NBR 8112 were realized with briquettes of sabiá's wood. It is known that the briquette has a higher potential heat because it has a higher fixed carbon content then the "in natura" species. This confers a higher superior calorific power, since the wood as a briquette takes longer to be burned in a reactor.

The ashes content obtained was low which allows us to affirm that the biomass has good characteristics for gasification, avoiding corrosion problems on the gasification process and environmental problems.

These data show a significant amount of calorific value, the sabiá's wood reaches 50% of value of petroleum coke , about 17,000 J/g its HHV when in form of briquette. So, it is clear that this biomass can be used as a auxiliary fuel or as fuel in a gasification process, with the advantage of being a natural raw material, with low cost and less polluting source of energy.

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