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COMBUSTION PERFORMANCE ASSESSMENT FOR RESIDUAL BIOMASSES: EUCALYPTUS (SAWDUST), BOCAIÚVA (SHELL), CRAMBE (BAGASSE)

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Abstract. *Given the present concern about the decrease of fossil fuels supply, and taking into account their contribution to the greenhouse effect, several studies propose different solutions to the problem. Among these solutions, there is the use of biomass. It is considered to be a clean and renewable energy, which can be used for heating and obtaining electricity, and has been drawing attention because of its availability and variety, as it is obtained from waste and exploration sources. The characterization of this energy source is essential for the selection of the type that will bring the most benefits and efficiency. A method that can be used is the "Combustion Index" (ICOM), which relates during combustion process, the burning time, increase in temperatures and decrease of fuel mass (biomass consumed). This work is a study of biomass combustion characteristics through ICOM and mass residues quantification after combustor burning, for three typical biomasses at the Cerrado, a biome from Brazil´s Central-West region: forest biomass (Eucalyptus), residual biomass from extractive harvesting activities (Bocaíuva) and waste to energy biomass from industrial activities (Crambe).*

Keywords: *Combustion index; Characterization; Renewable energy; Bioenergy.*

1. INTRODUCTION

Environmentally friendly fuels have been extensively discussed, as replacement on fossil fuels, due to industrial growth and its consequences, such as pollution, greenhouse gas emissions and scarcity of fossil energy sources. In this environmental protective scenario, the use of waste to energy solid fuels, as biomass, is intended to replace in whole or in part current fossil fuels. This alternative has the objective of reducing greenhouse gas emissions and making the industries independent of fossil and non-renewable fuels.

The use of fossil fuels for energy obtaining for both heat generation on an industrial scale and for cogeneration, are largely responsible for the emission of pollutants, and have increasingly harmed the environment. Faced with this, research in the area of renewable energy sources has gained prominence in the scientific community. According to the International Energy Agency Word Energy Outlook (2011), the use of biomass in the last decade increased from 8% of total world primary supply to 10% and is expected to increase even further to a value between 25% and 33 % by 2050.

In 2012, Brazil´s electricity generated from thermoelectric power-plants represented ~23.9% in the national electrical energy matrix, and from that total, biomass fuel represented ~30.4% (PEREIRA, 2014). Biomass has a neutral CO2 emission potential, as it is able to catch carbon from the atmosphere during photosynthesis and release the carbon back in the combustion, which contributes to a smaller cycle. For this, it is used as an alternative energy source to coal. Furthermore, biomass combined with coal (cofiring or co-combustion), has gained ground in research for heat generation and electricity cogeneration, once it is able to reduce the level of emission pollutants of SO2 in ~19.1% and NOx ~10.0% (Pereira and Bazzo, 2009).

In Brazil, biomass accounts for 66.475 million tons of oil equivalent, the second main source of energy (MME, 2008). In Brazil´s Central-West region, the culture of Crambe (*Crambe abyssinica Hochst*) planting is emerging and currently generates about 60% in mass of waste (bagasse) in the extraction of oil for biodiesel, which can be utilized as a thermal energy source (PEREIRA, 2014). The Bocaiúva (*Acrocomia aculeate*), typical from Brazil´s Cerrado, with a high oil content (about 70%) also used in biodiesel production, generates waste, where the shell has a great energy potential. Due to the growth of the cellulose industry in the region, the Eucalyptus cultivation is an agricultural crop, with a significant number of planted areas. According BRACELPA (2012), there are about 2.2 million hectares, which also present itself as an alternative source of biomass.

A method of comparing the performance of different types of biomasses as fuels is with the ICOM combustion index. According to Quirino (1991), ICOM index is able to characterize the behavior of solid fuels during combustion, and is obtained with an experiment that relates three parameters: change in mass of the biomass, the temperature reached during combustion and burning time. In terms of co-firing, ICOM is shown as a tool that allows to relate different types of biomasses according to this index. According to Pincelli (2011), the higher the value, the better the quality of the material under analysis, so it is possible to relate a high ICOM's biomass with a low one, thus obtaining a better use of the biomass (or waste to energy residues) and coal.

2. METODOLOGY

Three types of biomass samples were used, characterizing in a certain way the Brazil´s Central-West region. Bocaiúva as biomass available at Cerrado biome, Crambe as industrial processes residues (biodiesel industries, for example) and Eucalyptus as industrial surplus in land field (as examples: paper and pulp, charcoal, among others). The eucalyptus species specification is not addressed in this work, once it was obtained from commercial pack available at Dourados-MS for residential use.

The proximate analysis was performed according to standard NBR 8112 (ABNT, 1996). Obtained parameters were Moisture levels, volatile matter, ash and fixed carbon content. The results are presented in Tab. 2.

2.1 Combustion Index (ICOM)

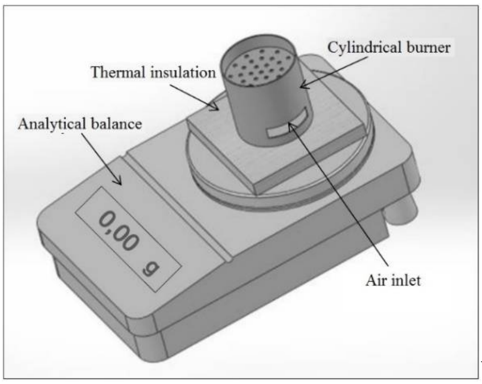
To evaluate the performance of these biomasses during combustion, the construction of a cylindrical burner was necessary. It has 98.60mm in diameter and a height of 121.28mm as in Figure.1. Biomass was located on a grate above a heat source for initial ignition. The construction includes an air inlet, with dimensions of 19.20 x 67.47mm, in the lower region, locating itself 51.30mm below the grid. The grid was constructed with zinc with holes about 1mm in diameter each, and approximately 10mm distance between themselves. A Petri plate with dimensions of 60 x 13mm was used to put the ignition fuel, in this case, hydrous ethanol. The proportion used was 5g of dry biomass for each 7,5ml ethanol.

For the temperature, measurements were made using a thermocouple placed directly above the combustion biomass, attached to a claw on a tripod, so it measured the temperature of the combustion gases. The entire apparatus was put on the analytical balance, thermally insulated by a wooden board with 2 cm thickness. A stopwatch obtained the burning time every 10 seconds, so that the three measurements were obtained simultaneously.

This apparatus makes it possible to check the temperature of the mass being consumed and the time variation during combustion. This allows drawing temperature curves, time *versus* mass, and time *versus* temperature. From values at characteristic points of these curves, it was possible to characterize the different biomasses by ICOM (QUIRINO 1991). The Table.1 shows the instrumentation and Figure. 1 shows the experimental instrumentation bench.

Table 1: Instrumentation technical specification.

Instruments	Measurements	Capacity	Precision
Analytical balance Bell S2202	Mass	Max. 2200g	±0,01g
Termocouple HANNA	Temperature	Max. 900°C	
Thermometry TENMARS TM-363	Temperature		±0,10°C
Stopwatch CRONOBIO SW2018	Time		±0,001s


a)


b)

Figure 1: a) ICOM Workbench: burner, thermocouple and analytical balance. b) Bench scheme at Solidworks, (PESSOA FILHO, 2013).

Before mounting the bench, the balance was tared with the mass of the burner, the mass of the thermal insulation and the mass of the Petri plate, totalling 407g. Then the biomass was placed on the grid of the burner and ethanol (liquid fuel) in the Petri plate below the grid. Thus, the mass to be measured by the analytical balance would be the mass of ethanol and biomass in combustion. From the moment of ignition of the ethanol, the time, the mass data and temperatures were measured simultaneously. The results were used to calculate the ICOM, as shown in Table 3, and for plotting the graphs. In all tests the burning of ethanol was considered in the measurments.

2.2 ICOM calculation

The combustion index was calculated using the following equation, based on the methodology of Quirino (1991):

$$ICOM = A.B/(100.C) \tag{1}$$

The original equation was adapted by the authors to the temperature conditions obtained by the tests performed with the three types of biomass. The determined parameters are given below, with reference to the temperature of 92.6 °C, which is 75% lower maximum temperature reached in the experiments with all three types of biomass, in this case, the Crambe (123.5 °C).

- ✓ A = percentage of test time in which the temperature remains above 92.6 ºC taken on the total combustion time of the biomass in question;
- ✓ B = percentage of the maximum temperature reached in the test, in relation to temperature 92.6 ºC;
- ✓ C = percentage of the total mass consumed generating temperatures above 92.6 °C;

ICOM is a dimensionless quantity, but not a typical non-dimensional number. It is still possible to assess this result in graphical analysis of the results of the biomass combustion performance. Reference results (Quirino, 1991) are used for comparison and discussion, and available in Figure 2. The solid fuel used by that author was a briquette named “BR2”, see in results section proximate analysis and ICOM (obtained according to the methodology presented in this work).

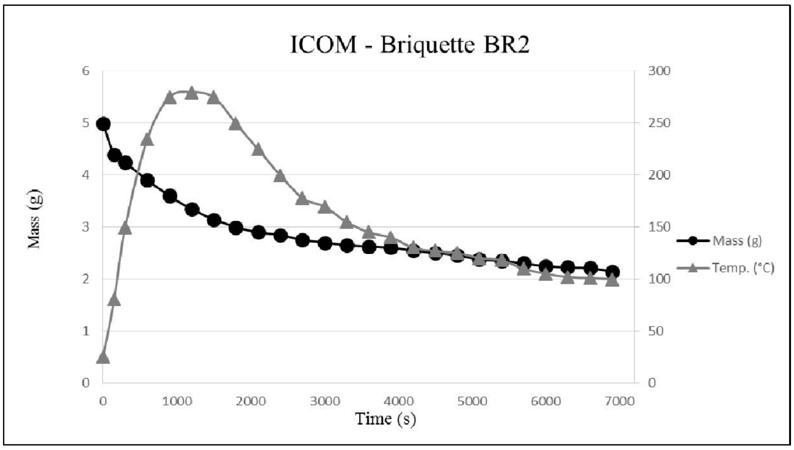


Figure 2: Combustion performance - BR2 as solid fuel. (QUIRINO, 1991)

2.3 After burning residues quantification (ash plus non-burned biomass)

After combustor burning process for ICOM determination, there are biomass residues left in the combustor grid, that have been reserved, of which 1g was separated for additional analysis. Once that these residues are not only ashes, but ash plus non-burned biomass, it is important to determine the non-burned biomass quantity (organic matter) in the combustion process. That was performed by ash determination (inorganic matter), according to NBR 8112 (ABNT, 1996). The ash content was then calculated by the following equation:

$$AC(\%) = [(m1 - m0)/m]100 \tag{2}$$

Where *AC* is the ash content in %; *m0* = crucible mass, in grams; *m1* = mass of the crucible + after burning residues in g; *m* = mass of the sample, in grams.

The results of that after burning residues quantification are presented in Table 4, results section.

3. EXPERIMENTAL RESULTS

The whole tests behaviors (experimental curves obtained) are available Figures (3), (4) and (5), respectively for Eucalyptus, Bocaiúva and Crambe, combustion processes occurring in the combustor (Fig. (1)). A total of 5g of solid fuel was used to evaluate the combustion process behavior for all three biomasses in this work.

Unlike other biomasses, Eucalyptus maintains a high temperature range (above the reference temperature 92.6 °C) for a longer combustion time. In addition, the fuel mass consumption at experimental data indicates that the combustion is of better quality due to the higher solid fuel consumption (or burning) relative to the other biomasses, see Fig. (3).

In fig (4), mass loss experimental data for Bocaiúva shows that solid fuel mass consumption does not occur until the highest temperature (when ethanol ends, see details at methodology section, item 2.1 in this work), indicating that the biomass does not sustain combustion without a heat source (ethanol liquid fuel combustion). As a result, it has the second lowest result in terms of solid fuel mass consumption, among all three biomasses in this work. Although this biomass has the highest temperature after Eucalyptus, its ICOM is the lowest.

In Fig, (5), related to the total experiment time, Crambe has been shown to keep the combustion for a longer period of time above 92.6 °C, when compared to Bocaiúva. However, its solid fuel mass consumption was very low, which can be seen in the experimental data. That behavior can be explained by the fact that the mass of organic matter in the residues after burning process is greater than the Bocaiúva (see Table 4 for details).

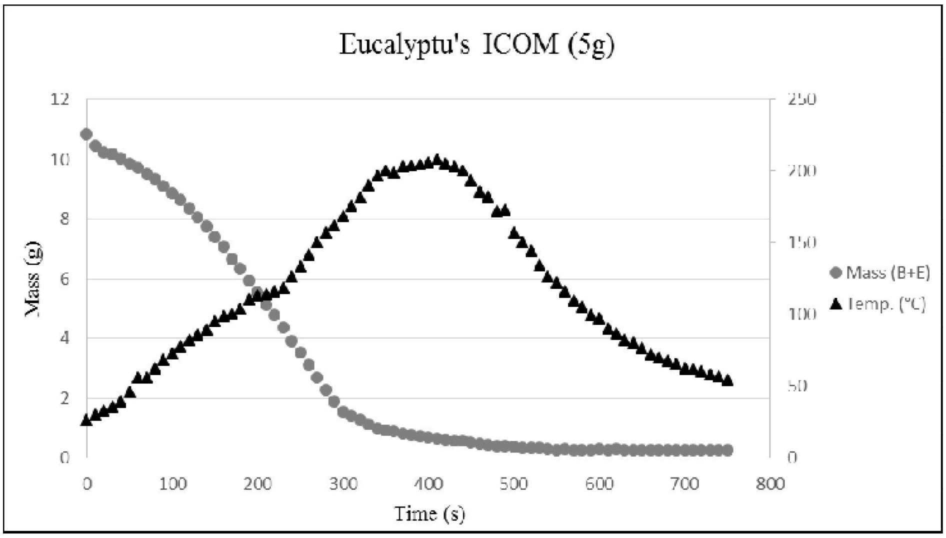


Figure 3: Combustion performance – Eucalyptus as solid fuel.

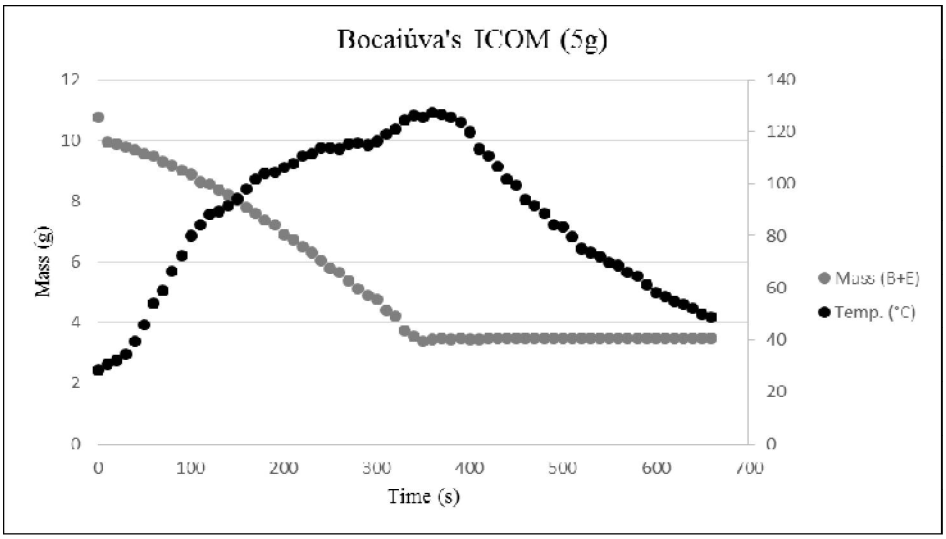


Figure 4: Combustion performance - Bocaiúva as solid fuel.

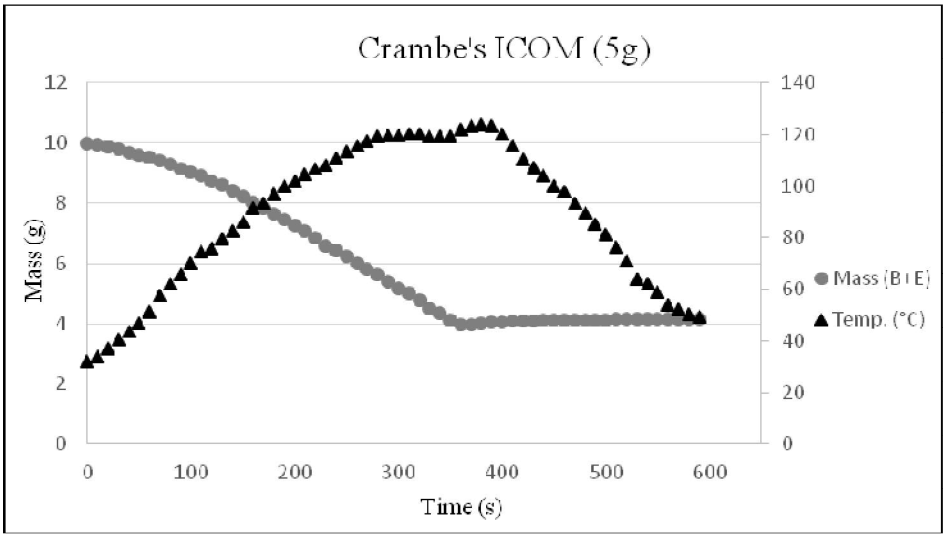


Figure 5: Combustion performance - BR2 as solid fuel.

Table (2) present proximate analysis and HHV results for three biomasses under evaluation in the present work (Leal da Silva, *et al*, 2014) and for Briquette BR2 (Quirino, 1991).

Table 2: Proximate analysis and HHV - Bocaiúva, Eucalyptus, Crambe and "BR2" [1].

	Moisture Content (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon Content (%)	HHV (MJ/kg)
Bocaiúva Shell	7.99 ± 0.60	74.92 ± 1.19	3.51 ± 0.73	21.36 ± 1.51	19.07
Eucalyptus Wood	6,86 ± 0.58	82,67 ± 1.10	1,62 ± 0.87	15,71 ± 1.23	20.71
Crambe Bagasse	8.00 ± 0.67	76.74 ± 1.05	7.14 ± 1.21	15.68 ± 2.14	17.79
Briquette BR2 [1]	0.49	20.21	36.54	43.27	19.68

[1] Briquette BR2 from Quirino (1991).

Combustion index (ICOM) is indicated in Table (3), as well as Eq. (1) parameters, measured at UFGD laboratory tests. In summary, there are available fuel mass consumption parameters, combustion temperature and total experiment time. These values represent the tests as resumed as possible, including the variables for calculating ICOM index.

Table 3: Parameters obtained in tests - ICOM determination.

	Eucalyptus Sawdust	Bocaiúva Shell	Crambe Bagasse	Briquette BR2 [2]
Experiment time (s)	750	660	590	<7200 [2]
Max. Temp. (°C)	208.4	127.2	123.5	280
Mass consumption (g)	4.74	1.21	0.50	2.85
A	61.333	48.485	52.542	93.730
B	225.054	137.365	133.369	302.376
C	65.622	42.419	37.200	57.000
ICOM index	2.103	1.570	1.884	4.973

[2] Time until 100 °C.

From the Table 3, it is noted that Eucalyptus biomass was the solid fuel which burned mass was most effective during combustion process, followed by Bocaiúva and Crambe biomasses. Maximum temperatures obtained, Eucalyptus also stood out, followed again by Bocaiúva and Crambe. Consequently, ICOM index for Eucalyptus resulted in the highest value.

Still discussing Table (3), a very high value for ICOM index for the briquette BR2 as solid fuel is observed. It is worth mentioning that the reference temperature used for the calculation of that index, for all Table (3), was the methodology from the present work and not the reference temperature used in the bibliography. This explains the high ICOM index value BR2, because its higher temperature is rather higher relative to the other, which influences the parameters A and B (form Eq. (1)), which are dependent on the temperature.

Figures (6) and (7) are discussed next, in order to have a representative comparison to literature available in the subject, that is, comparison for ICOM index. The experimental data for “BR2” burning as well as for Eucalyptus, Crambe and Bocaiúva, were normalized in order to get a better representation of the combustion behavior for different solid fuels. Furthermore, normalizing facilitates the interpretation and comparison even though the literature results have a larger time scale of combustion. In that way, x-axis (Δt) and y-axis (ΔT and Δm) values are divided by the highest value obtained for each one of the solid fuels, in their original experimental data.

Burning time difference occurs mainly due to the fact that solid fuel density, as example for “BR2” (briquette) is much higher than those biomasses evaluated in this work (milled biomass). Based on the proximate analysis results for “BR2” (QUIRINO, 1991), see Table 2, some considerations were necessary to understand the performance differences between that solid fuel and the others evaluated in this work. Final temperatures, when normalized time is equal to unity, are ~100°C for “BR2”, while it is ~50°C for the three biomasses in this work. It does not affect ICOM determination and comparisons in Table (3).

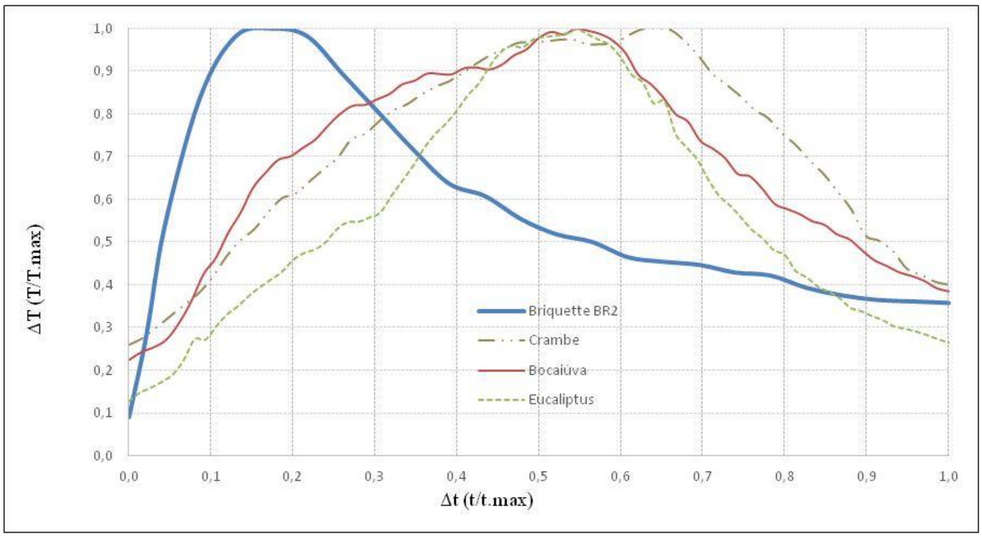


Figure 6: Temperature variation in the combustion process (normalized values).

Since the “BR2” is assumed to be a solid fuel (biomass with a low moisture content and volatile matter), it has the highest heating value and therefore best combustion performance, both by ICOM index and combustion parameters behavior in Fig. (6). Temperature peak occurs at the beginning of the test, falling thereafter (Figure 2), unlike other three solid fuels evaluated, where temperature peaks occur in the middle of the test. Maximum temperature reached by “BR2” is the highest among other solid fuels (~275°C, see Figure 2). It is still possible to observe, in Figure 6, that the combustion behavior for the other solid fuels (Crambe, Bocaiúva and Eucalyptus) is similar to the behavior from the literature (Quirino, 1991). In other words, they follow a common pattern: reaching maximum temperature and next dropping it, in their own characteristic combustion normalized time (time < 20% for “BR2” and ~50-60% for others).

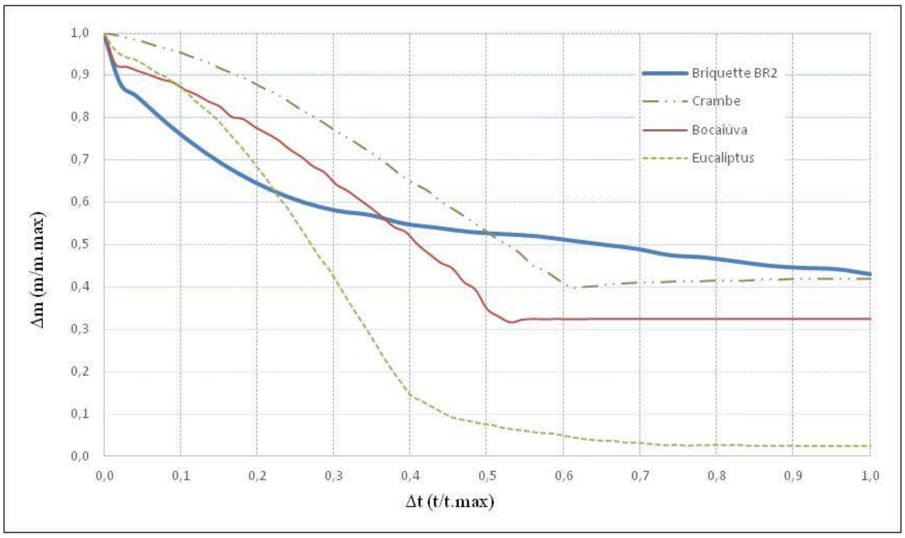


Figure 7: Mass variation in combustion process (normalized values).

Figure (7) shows fuel mass consumption normalized behavior. Remaining mass (ash plus non-burned biomass) in the combustion process is higher for "BR2" (> 40%), while lowest values are for Eucalyptus (< 5%). That is corroborated by Tab. (2) results, were ash content in "BR2" is much higher (~36%) than in other residual biomasses (<10%). Still from Tab, (2), while HHV for "BR2" is the highest value and a good characteristic as solid fuel, highest ash content is a bad characteristic, thus showing a quite different behavior in comparison to the results obtained by authors in this work. Similarly to results in Fig. (6), results in Fig(7) follow a common pattern: reaching minimum mass values (or maximum mass loss, due to combustion) and, next, stabilization of the mass variation (Δm~ 43%, ~ 42%, ~ 32% and ~3%, respectively for "BR2", Bocaiúva, Crambe and Eucalyptus).

Table (4) indicates the after burning residues quantification (ash plus non-burned biomass), given in terms of mass values (g) and its percentage (%) relative to mass residues or original fuel mass. As pointed out in methodology section, ash content is determined according to Eq. (2). The results obtained indicates the combustion process performance in its ability to fully burn the solid fuel available, or in other words, the biomass performance to be burned, quantified by ICOM index. The greater the mass residues, the worst is the solid fuel combustion, in this case is the Crambe Bagasse (line 1) and the best being Eucalyptus. In the other hand, the greater the ash content (line 4 and 11), the worst is the solid fuel proximate analysis characteristics for combustion, in this case also is the Crambe Bagasse (see also, Table (2)) and the best being Eucalyptus. In general, only Eucalyptus was able to sustain combustion all over the test, once it had 94.8% of the original biomass fully burned. That does not indicates Bocaiúva and Crambe are bad solid fuels, see HHV at Table (2), in fact both have ash content lower than 10%, but require a combustion process more stable to provide fully burning and does not allow flame off in the combustor.

Table 4: After burning analysis (ash content plus non-burned solid fuel).

	Eucalyptus Sawdust	Bocaiúva Shell	Crambe Bagasse
Mass residues (g), after burning of 5g of solid fuel	0.26	3.79	4.50
Mass residues (%), after burning of 5g of solid fuel	5.2	75.8	90.0
Ash content (g) – inorganic matter, from Eq. (2)	0.055	0.144	0.315
Ash content (%) – inorganic matter, from Eq. (2)	21.0	5.0	9.0
Non-burned biomass (g) – organic matter	0.210	3.650	4.180
Non-burned biomass (%) - organic matter	91.90	97.15	95.82
Burned biomass (%) – at ICOM index determination	94.8	24.2	10.0
Ash content (%), relative to original 5g of solid fuel	1.10	2.88	6.30

4. CONCLUSIONS

This paper presented a study on combustion performance for three different biomasses typically found at Brazil´s Central-West region, aiming to understand combustion characteristics for single firing and also for future studies on cofiring (with coal and other residues). From results obtained, main highlights are pointed out next:

a) Combustion performance is of better quality for Eucalyptus, which maintains a high temperature range together with good fuel mass consumption;

b) Bocaiúva as solid fuel depends on a heat source to sustain combustion in order to have its total mass fully burned;

c) Crambe sustains combustion for a longer time than Bocaiúva, but has the highest non-burned fuel mass remained;

d) ICOM index is higher for Eucalyptus sawdust (2.103), followed by Crambe Bagasse (1.884) and Bocaiúva shell (1.570). The Crambe excelled over the Bocaiúva because a great amount of the initial mass was consumed in its temperature range, as well as Eucalyptus when compared with both. ICOM´s parameter "A" is the main reason to the differences between Crambe's ICOM and Bocaiúva's. When compared to "BR2" briquette, it is even higher due to its energy densification process (briquetting);

e) Normalized temperature and time indicates that Eucalyptus sawdust is prominent in both parameters. It took longer to reach its highest temperature, but was able to self-sustain its full burning (94.8% of burned biomass);

f) Second best combustion performance is for Bocaiúva Shell with 24.2% of burned biomass and reaches higher temperature when compared to Crambe Bagasse. Bocaiúva Shell also has HHV smaller than the one for Eucalyptus Sawdust and higher than the one for Crambe Bagasse.

g) "BR2" briquette, as reference solid fuel for comparison, its great performance is given by the fact that this biomass is pre-treated (densification) but its HHV heating value is not quite different from the others in this work, seet Table (2). However, its fixed carbon content stands out, which explains the excellent performance in the combustion. Physical

characteristics such as particle size and density (BR2 is a compressed biomass) also allowed this biomass to reach higher temperatures and a longer period of combustion.
h) After burner analysis, that gives the amount of ash and non-burned solid fuel, indicated that Eucalyptus sawdust has the lowest ash content and also the lowest non-burned biomass. These parameters, which indicated better combustion characteristics, are followed by Bocaiuva shell and Crambe bagasse;

All considered, authors conclude that Eucalyptus sawdust has the best combustion performance, followed by Bocaiúva shell and Crambe bagasse. As the research is ongoing, cofiring (with coal) must prioritize the same sequence, while when cofiring these two or three biomasses combined among them, it is more convenient to prioritize the use of the other two biomasses combined with Eucalyptus. However, it is noteworthy that the use of residual biomass (Brazil´s Central-West region), both as pure and cofiring for industrial purposes, depends on the offer, and quantitative availability must be considered. Literature indicated cofiring as a good option to reduce emissions in coal power plants, but in Brazil, that has a great diversity on biomass species and quantities, low scale power plants (< 10 kW) with cofiring of two or three different biomasses is an interesting possibility.

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