Evaluation of Fuel Properties of Charcoal Briquettes Derived From Combinations of Coconut Shell, Corn Cob and Sugarcane Bagasse

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Abstract: The study aims to evaluate the fuel properties of charcoal briquettes made from combinations of coconut shell, corn cob and sugarcane bagasse at specified ratios. In the study, single (100%), double (50%-50%) and triple (33%-33%-33%, 50%-25%-25%, 50%-37.5%-12.5%) constituent briquettes were produced with compaction pressures of 2.2 MPa, 4.4 MPa and 6.6 MPa. The fuel properties evaluated are calorific value as well as density, relaxation and compaction ratios. Blending combinations of charcoal from different raw materials showed an improvement in the calorific value. Among the multiple constituent briquettes, 50% coconut shell – 25% corn cob – 25% sugarcane bagasse combination yielded the highest calorific value at 19951.4 J/g which was comparable to coconut shell charcoal, having the highest calorific value among all charcoal at 21693.3 J/g. The compaction pressure had a significant effect only on the volume displacement of the briquettes due to more void space in the raw materials that can be filled up upon the application of higher compaction pressure. The mixture ratio greatly affected the stability and calorific value of the product briquettes

Key Words: charcoal briquettes; relaxation ratio, compaction ratio; calorific value

1. INTRODUCTION

The Philippines, being an agricultural country, is abundant of agricultural products. The major crops produced are sugarcane, rice, coconut, banana and corn with volume of production by the Philippines in 2013 of 2.5 x 10^7, 1.8 x 10^7, 1.5 x 10^7, 8.6 x 10^6 and 7.4 x 10^6 metric tons respectively (Bureau of Agricultural Statistics, 2013). Accompanying the large volume of crop production is the generation of large amounts of agricultural wastes. Agricultural wastes have been known to be good sources of biomass. One technology used in utilizing these wastes is biomass briquetting which involves the densification of the biomass materials through the application of pressure. Some of the advantages of briquetting are as follows: there is an increase in the bulk density of the material which makes it easier to transport and store, there is higher energy content per unit volume of the material and it enables the production of a homogenous product fuel from different raw materials (Chaney, 2010).

Some criteria used in determining the quality of charcoal briquettes are as follows: initial, maximum and relaxed density, calorific value, and the proximate and ultimate analyses (Oladeji, 2010). The initial, maximum and relaxed densities are measured before briquetting, immediately after removal from briquetting machine and after a specified period of time, respectively. The densities provide information on the stability of the briquettes. In assessing the performance of briquettes as fuel, the calorific value is the primarily considered because it is the amount of heat produced by the briquettes when burned.

Consequently, the calorific value can be used to evaluate the performance of the major agricultural wastes as fuel. Banana peelings, which have a higher volume of production compared to corn cob, are said to be less feasible in being utilized as fuel because of its heating value which is 3830 J/g (Kamsonlian, et al., 2011). To compare, the caloric value of corn cob was found to be 20890 J/g (Oladeji, 2010). As for rice hulls, which are wastes derived from the production of rice which is the most produced crop in the Philippines, the heating value is 18400 J/g. Furthermore, coconut shell, being one of the abundant agricultural wastes in the Philippines, has a heating value of 20880 J/g (Sundaram & Natarajan, 2009). Also, sugarcane bagasse has a heating value 19200 J/g (Tiwari et al., 2011). Based from the calorific values, coconut shell, corn cob and sugarcane bagasse are raw materials considered in the study as these are the raw materials with the greatest potential compared to other agricultural wastes in the Philippines.

Biomass containing a single component is possible to produce from the said wastes. However, a study from the Department of Environment and Natural Resources revealed that there are certain combinations of agricultural wastes that yield better heating values compared to its individual components. A study by Conti et al. (2000) briquettes made from 50% coconut shell, 50% corn cob yielded a calorific value of 24238 J/g. The calorific value of the briquette combination was higher than reported calorific values of briquettes made from the individual components. A study by Musa (2012) also reported an increase in calorific value of briquettes from combined raw materials. In their study, the measured calorific value of charcoal briquette composed of 50% groundnut shell and 50% sawdust briquette was 19860 J/g. However, the study cited that the calorific values of groundnut shell and sawdust briquettes are 17800 J/g and 18800 J/g, respectively. From these findings, there is a potential of increasing further the calorific value of briquettes by combining corn cob, coconut shell and sugarcane bagasse. However, there have been no studies found on combining the three wastes for briquetting. This study aims to determine if there is a significant increase in calorific value of briquettes produced from a combination of corn cob, coconut shell and sugarcane bagasse.

2. METHODOLOGY

2.1 Collection and drying of raw materials

The raw materials used in this study were collected from their respective supplier. Coconut shell (CS) were obtained from Lozada Market, Las Pinas, white Corn Cob (CC) were obtained from Tarlac, Sugarcane Bagasse (SB) were acquired from Pampanga Sugar Development Company. Cassava starch on the other hand, which was used as binder, was purchased from the local market. The raw materials were separately sun-dried for three days until constant weight was achieved.

2.2 Pyrolysis and size reduction

The partially dried raw material underwent pyrolysis using the drum kiln in the Materials Recovery Facility (MRF) in Barangay Palacpalac, Victoria, Tarlac. The kiln is a modified 238-Ldrum. The raw materials were processed separately that is only one type of agricultural waste is pyrolyzed at a time.

Two barrels were used in the drum kiln. The smaller barrel contained the biomass and the other contained the fuel. The biomass was put inside the smaller barrel and a lid was used to cover the barrel. However, it was made sure that the lid was not air tight to avoid the buildup of pressure during heating. The lid was loosely fitted such that the contents were secured but gases from pyrolysis could escape. This is to enable pyrolysis gases to also combust after release from the small barrel in order to help sustain the reaction.

The larger outer barrel was erected and about 12.7 centimeters of fuel, primarily wood, were placed in the bottom of the large barrel. The outer barrel had holes with a diameter of 1.3 centimeters in its sides to allow air to flow inside the barrel. Air flow is needed to sustain the combustion of fuel. The smaller barrel was inserted into the larger barrel upside down, resting on sticks that were placed in order to provide clearance of about 12.7 centimeters from the bottom of the smaller barrel to the bottom of the larger barrel. A chimney was then placed above the outer barrel. The primary purpose of the chimney is to serve as point of release of combustion gases as well as create an updraft of air. Also, there is an opening below the larger barrel to ignite the fuel and to add more if necessary to sustain the pyrolysis.

The fuel was then ignited in order to start combustion. The set-up allowed the combustion of fuel at the bottom of the outer barrel to heat up the small barrel and ultimately the agricultural waste inside. The heating up of biomass in little to no oxygen promoted pyrolysis. Wood fuel was added accordingly to sustain the combustion of fuel. Pyrolysis continued until the burning stopped and the system cooled down.

Pyrolyzed raw materials were subjected to a hammer mill equipped with a mesh size of 20, equivalent to a particle size of 0.841 mm. The 20-mesh screen was the only available in the hammer mill of the MRF. The grinded raw materials were immediately placed in labeled rice sacks in order to avoid additional absorption of moisture. The rice sacks were then put inside plastic disposable bags and sealed with rope and tape for more secure storage.

2.3 Mixing of specified combination of charcoal powder-binder ratio

The double constituent mixture consisted of 50:50 by weight ratio of two agricultural waste charcoals. For briquettes with three constituents, the following ratios were used: 33.33%, 12.5%-37.5%-50% and 25%-25%-50% by weight of each type of charcoal. The ratios were chosen in order to study the effect of the amount of raw materials relative to each other on the fuel properties of briquettes. 6% binder ratio was used as baseline ratio on the three agricultural wastes. For all mixtures, the proportion used was 100 grams charcoal, 100 grams water and 6 grams of cassava starch.

2.4 Briquetting of charcoal mixture

The combined binder and mixture of agricultural waste were put into a molder and compressed using carver press to produce hollow cylindrical briquette. The dimensions of the molder were 5 cm outer diameter, 1.5 cm inner diameter and 4cm height. For each type/ratio of briquette, three sets of compaction were done with differing compaction load: 400 kg, 800 kg and 1200 kg. Taking into consideration the area of the briquette mold, the resulting compaction pressures are 2.2, 4.4 and 6.6 MPa. Triplicates run were done per compaction pressure. After the compaction of the charcoal mixture, the resulting briquette was removed. The base was first removed from the molder set-up. The plunger was used to press again against the briquette which was then inside the mold. The briquettes produced were still wet because of the binder therefore careful handling was done. After briquetting, the briquettes were dried in a convection oven at 149 degrees Celsius until constant weight was achieved for final drying. The dried briquettes were then stored inside airtight plastic containers to prevent the absorption of moisture.

2.5 Characterization of charcoal mixtures

The calorific values of the different charcoal combinations were measured using Parr adiabatic bomb calorimeter in accordance with ASTM D 2015-96 which is the Standard Test Method for Gross Calorific Value of Coal and Coke by the Adiabatic Bomb Calorimeter.

The Department of Science and Technology (DOST) was commissioned to perform the proximate and ultimate analysis. Since the 50% shell – 25% bagasse – 25% corn cob yielded the highest calorific value among the multi-constituent briquette ratio, the combination was tested for proximate and ultimate analysis. The calorific value was the criterion considered because it is considered to be the most important fuel property therefore the best metric when comparing charcoal (Veeresh, et al., 2012).

In performing the experimental analysis of this study, the controlled variables were the particle size of the raw material, pyrolysis holding temperature, briquetting temperature, binder, which was expressed in terms of weight by percentage. The independent variables were the compaction pressure of the briquetting machine and the raw material charcoal combinations. Three levels of compaction pressure were applied, namely 2.2 MPa, 4.4 MPa and 6.6 MPa. Furthermore, the raw material ratios studied were single (100%), double (50%-50%) and triple (33%-33%-33%, 50%-25%-25%, 50%-37.5%-12.5%) constituents. On the other hand, the dependent variables are calorific value, and initial, maximum and relaxed density.

The calorific value was measured against all the raw material ratios in replicates. On the other hand, the initial, maximum and relaxed densities were measured against the three compaction pressures for all raw material ratios. The density, relaxed and compaction ratios were determined as an indicator of better stability.

2.6 Statistical Analysis

The statistical treatment of data was done using the software Minitab. The distribution plot of the calorific value, initial, maximum and relaxed density data were analyzed to check for normal distribution. Levene tests were also conducted for the calorific value, initial, maximum and relaxed density data to check for homogeneity of variances. The data which were found to be normally distributed but had unequal variances were then subjected to Welch Analysis of Variance (ANOVA) test. On the other hand, data which were normally distributed and had equal variances were subjected to One-way ANOVA.

3. RESULTS AND DISCUSSION

Figure 1 show the measured net calorific values of each charcoal combination. Combinations with high sugarcane bagasse content resulted in low calorific value since sugarcane bagasse has the lowest energy density among the three raw materials. However, it can be observed that by blending more coconut shell, a raw material considered to have high density, higher calorific value can be achieved. Blending the raw material with high calorific value to a raw material with low calorific value greatly enhanced the calorific value of the briquette. It is important to note that the charcoal combination with the highest calorific value was 50-25-25 coconut shell, corn cob and sugarcane bagasse with 19951.40 J/g. The study of Conti et al., (2000) similarly reported that by blending different agricultural wastes the improved the calorific value.

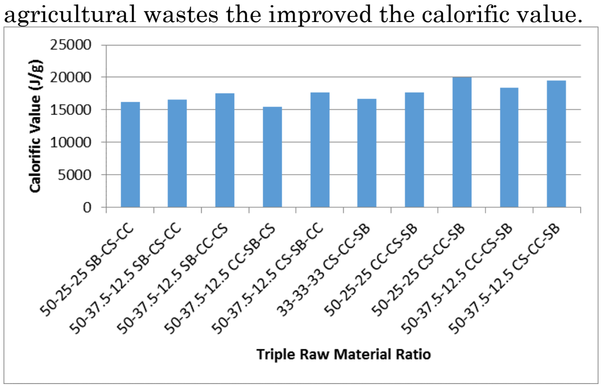

Fig. 1 Profile of Net Calorific Value versus Triple Raw Material Constituent

Figure 2 show that the compaction ratios increased with increasing the compaction pressure. For higher content of corn cob and sugarcane bagasse, higher compaction ratio was achieved. This means briquettes with more corn cob and sugarcane bagasse charcoal achieved more volume displacement compared to those with more coconut shells. Higher compaction ratio means more voids in the pre-compressed material (Oladeji, 2010). It is an indication of greater volume displacement which is a positive attribute for transportation and storage. The application of pressure up to 6.6 MPa greatly affected the briquette with higher bagasse and corn content since they yielded a high value of compaction ratio.

On the other hand, the mixture ratio that was chosen to be tested for proximate and ultimate analysis is the 50% Shell – 25% Bagasse – 25% Corn Cob combination on the basis of calorific value. The particular combination yielded the highest calorific value among mixture ratios at 19951.40 J/g.

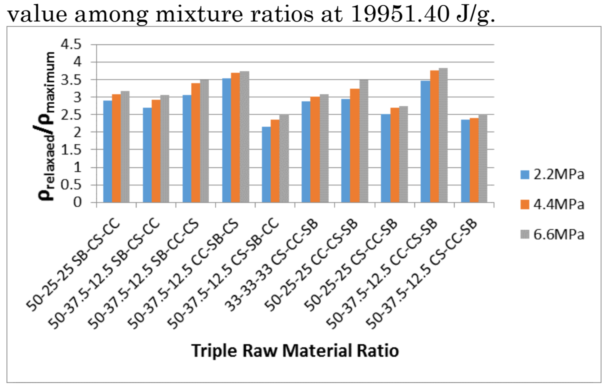

Fig. 2 Compaction ratio versus Raw Material Ratio

The proximate analysis of the 50-25-25 CS-SB-CC combination can be compared to the proximate analysis of the 100% CS charcoal which had the highest calorific value (21693.3 J/g) among all charcoal combinations tested in the study. Table 1 summarizes the proximate analysis of Coconut Shell Charcoal (Yerizam, 2013) and charcoal composed of 50% Shell – 25% Bagasse – 25% Corn Cob:

Table 1 Proximate Analysis of Coconut Shell Charcoal (Yerizam, 2013) and 50% Shell – 25% Bagasse – 25% Corn Cob Charcoal Combination

Component	100 CS(%w/w)	50-25-25 CS-SB-CC (%w/w)
Moisture	10.55	3.46
Volatile Combustible Matter	10.85	21.2
Ash	3.22	29.8
Fixed Carbon	78.32	49.0

Comparing the two charcoals, coconut shell charcoal contains higher fixed carbon percentage and lower ash content compared to the 50-25-25 CS-SB-CC combination. The difference in fixed carbon percentage can be considered to be one of the primary reasons why coconut shell charcoal has a higher calorific value compared to the sample briquette. However, the sample charcoal combination has higher volatile matter and moisture percentage compared to coconut shell charcoal. This is an indicator that the sample charcoal combination can have better flame length and ignition properties compared to coconut shell charcoal (United Nations Environment Program, 2006). From Table 1, it can be observed that the 50-25-25 CS-SB-CC combination was only able to meet the standard for good commercial briquette according to the FAO (1983) and EN 1860-2-2005 standard in the aspect of moisture content and binder used. The moisture content of the 50-25-25 CS-SB-CC briquette was 3.46%, lower than the value (5%-15%) suggested by the FAO (1983) This indicates that only a small part of the calorific value was lost because of the presence of moisture.

However, the 50-25-25 CS-SB-CC combination yielded a calorific value greater than the required for the purposes of grilling and cooking (16096 J/g) as well as for heating boilers (17421 J/g), as suggested by Baconguis (2006). Even though there were some aspects of the EN 1860-2-2005 standard that were not met by the 50-25-25 CS-SB-CC combination for barbecue purposes, the combination can still be used for cooking based from the calorific value.

The heating value of charcoal is greatly affected by its fixed carbon content since it gives a rough approximation of the heating value (United Nations Environment Program, 2006). The fixed carbon content of 49.0% of the charcoal is comparable to the fixed carbon content of the rest of the coal examples. In order to determine if the calorific value is comparable to the coal examples as it is in fixed carbon content, the Table 2 summarizes the calorific values.

Table 2 Net Calorific Values of Various Coals

Type	Calorific Value (J/g)
50% CS – 25% SB – 25% CC	19951.4
Indian Coal	16736
Indonesian Coal	23012
South African Coal	25104

From the table above, it can be observed that while the calorific value of the biomass charcoal (19951.4 J/g) is less than that of Indonesian (23012 J/g) and South African (25104 J/g), its value is not greatly different. Indian coal, which has less percent fixed carbon than the biomass charcoal also has less calorific value. The study was able to display the positive relationship between the fixed carbon content and calorific value.

On the other hand, the ultimate analysis typically includes elemental compositions such as Carbon, Hydrogen, Nitrogen, Sulfur and Oxygen. However, chemical analysis by DOST does not include the percent oxygen content. This can be approximated by subtracting the sum of percent carbon, hydrogen, nitrogen, sulfur and ash content from 100% (Volborth et al., 1978). This value obtained is "oxygen by difference". Table 3 summarizes the ultimate analysis of 50% Shell – 25% Bagasse – 25% Corn Cob briquette combination.

Table 3 Ultimate Analysis of 50% Shell – 25% Bagasse – 25% Corn Cob Briquette Combination

Carbon (%w/w)	65.3
Hydrogen (%w/w)	2.92
Nitrogen (%w/w)	0
Sulfur (%w/w)	0.101
Oxygen (%w/w)	10.479*

In order to automate the analysis of data, all the statistical analysis in the study were accomplished using Minitab software. Also, In order for One-way Analysis of Variance (ANOVA) to be effectively applied to the data on Calorific Value (CV) versus Mixture Ratio, the main assumptions of normal distribution and homogeneity of variances must be met. The Figure 3 shows the distribution plot of CV

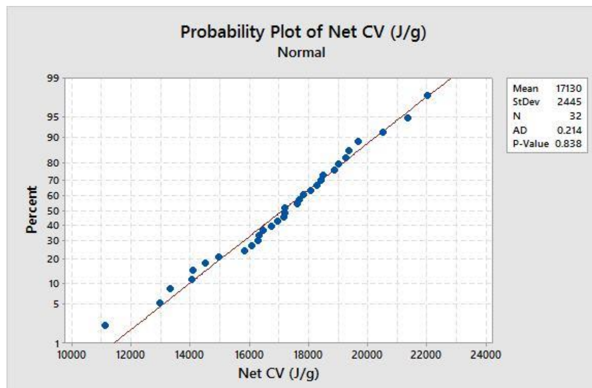

Figure 3 Probability Plot of Net Calorific Values

At an α-value of 0.05, the p-value is greater than the α-value. This signifies that the null hypothesis cannot be rejected and there is not enough evidence that the data are not normally distributed. In order to check for homogeneity of variances, a Levene test on the CV versus Mixture data was conducted. Based from the low p-value, equal variances cannot be assumed for the data. Based from the two conditions above, the Welch ANOVA test is more appropriate to use.

Since the p-value (<0.005) is less than α, one or more means in the data are significantly different. This indicates there are certain groups whose calorific values have means that are significantly different from the others. This suggests that the mixture ratio of those groups significantly affected the resulting calorific value compared to other ratios. This is an indication of the significant effect of raw material ratio on the calorific value.

4. CONCLUSIONS

This study proved that stable charcoal briquettes made from combinations of coconut shell, corn cob and sugarcane bagasse charcoal can be produced at the specified conditions. Even though the multi-constituent mixtures did not yield a higher calorific value than single-constituent charcoal, blending combinations of charcoal from different raw materials caused an improvement in the calorific value. Combinations with higher coconut shell content yielded higher calorific value compared to mixtures with high corn cob and sugarcane content. Coconut shell charcoal yielded the highest calorific value among all combinations while 50-25-25 coconut shell, corn cob and sugarcane bagasse combination had the highest calorific value for all muti-constituent mixtures. Even though the 50-25-25 coconut shell, corn cob and sugarcane bagasse combination did not meet all the standards for good commercial briquettes, the calorific value was enough for cooking and boiler heating purposes.

In the study, the compaction pressure had a significant effect only on the compaction ratio. The compaction pressure greatly affected the volume displacement of the briquettes. On the other hand, the mixture ratio had a significant effect on the calorific value, density, relaxation and compaction ratio. The ratio at which raw material charcoal were blended is a major factor on the stability and calorific value of the products.

Briquettes with higher coconut shell charcoal content yielded high density ratios which is an indicator of more stable briquettes. On other hand, higher compaction ratios were achieved with briquettes of high corn cob and sugarcane bagasse charcoal content. This signifies that more volume was displaced in the briquetting of the charcoal.

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