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Evaluation and Analysis of Coffee Husk and Coco Peat Briquettes as Biomass Fuel

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Abstract

The study evaluated and analysed the calorific values, burning rate, ignition rate, volatile matter, fixed carbon, ash and moisture contents of briquettes made of coffee husk, cocopeat, and their mixture, and briquettes needed to boil 1L water and strength of briquettes. Results revealed that coffee husk briquette (T_1) had highest calorific value of 3,919.36cal/g, cocopeat briquette (T_2) had lowest ash content of 5.79%. Lowest moisture content found in mixture (T_3) with 10.45% and lowest fixed carbon content was cocopeat with 17.28%. Test results on volatile matter, T_2 had highest with 76.93%, in burning rate T_1 had lowest with 6.61g/min. Results in specific fuel consumption T_1 had lowest value of 0.2116kg/liter. T_1 had fastest ignition rate with 0.03130mm/s compared to other treatments. Boiling test found T_1 briquettes had fastest boiling time of 10.67min to reach maximum temperature of 376.95ºC. Results on strength revealed that T_2 had highest strong point of force and stress with 22.8645kgf. Overall results showed that ash content, fixed carbon, volatile matter, strength, burning rate, specific fuel consumption, briquettes needed to boil 1L of water and ignition rate revealed significant differences among treatments while calorific values and moisture content showed no significant difference. Results revealed that T_1 had best fuel properties among others, in terms of calorific value, fixed carbon, volatile matter, and burning rate. T_1 had least briquettes used to boil 1L water. Among the treatments, T_2 endured greatest amount of force thus strongest. Briquettes from mixture of coffee husks and coco peat had lowest moisture content.

Keywords: Coffee Husk; Coco Peat; Briquettes; Biomass; Calorific values; Volatile matter

Introduction

Energy is very essential for several activities like generating heat, cooking, or as a fuel for automobiles. Renewable and non-renewable are the two forms of energy used by human in their daily life. Renewable resources are an energy source that cannot be depleted and are able to supply a continuous source of clean energy. Non-renewable energy sources are those which cannot be replenished and once they have been used, they become exhausted.

Biomass resources include a wide range of plant and animal materials available on a renewable or recurring basis, most widely available and used resources in the world (Walsh, 2004). It is a type of renewable source of energy that is used as a fuel and is obtained from organic matter. including energy crops and forest residues, agricultural food and feed crops, agricultural crop wastes, wood processing wastes, aquatic plants, animal wastes, municipal wastes and other waste materials.

Coffee is one of the top produced commodities and commercialized worldwide, the processing of coffee produces significant contribution of agricultural waste, ranging from 30% to 50% the weight of the total coffee produced, depending on the methods of processing. Husks of coffee and pulp are the main solid remains from the processing of coffee, for which there are no current lucrative uses, and their sufficient dumping contribute a major environmental problem. Thus, in agreement with the thought of sustainable development, advanced techniques and products for the lucrative and acceptable use of this type of biomass are being required (Oliveira, 2015). Coffee husks are referred to as coffee chaffs and considered to be the dried skin of the bean. Some of their common usages are to make them into fertilizer and as beddings for some pets and poultry. Husks of coffee are also an good material for briquetting available with 10 percent moisture content.

Coco peat is an organic, eco-friendly, and multipurpose natural product. It is usually brown in colors and is fibrous, mossy, dusty or soil-like in appearance. Once processed it is available in markets in varying forms such as in blocks, tablets and loose in bags or sacks. It is widely used as an alternate growing medium for plant crops because of its good aeration and high-water holding capacity. Cocopeat is a renewable and sustainable resource that is revolutionizing agriculture around the globe. As a growing medium, coco peat can also be used to produce a number of crop species with acceptable quality in the tropics (Awang, 2009).

The coconut fiber waste industries are coco peat or coir dust which is obtained after the extraction fiber from coconut husk and has a very limited usage. In the Philippines, a small percentage of coir dust is used for making compost and most of the coir dust is left as waste product in coconut producing provinces. Therefore, briquetting of coir dust from coconut has a great potentiality in the country. The world current production of coconuts has the potentialities to produce electricity, fibreboards, heat, animal feeds, organic fertilizer, and fuel additives for cleaner emissions. Moisture reduction of drying of biomass is a very practical way of increasing the heat efficiency and power generation, reducing emissions and improving the power plant operations (Svoboda et al. 2009).

The technology compacting can also be used to advance its handling characteristics, it improves the volumetric calorific value, it reduces transportation expenses and produces a uniform, stable and clean production of environment-friendly fuels (Demirbas et al., 2009; Wilaipon, 2007). Conversion of biomass into useful forms of energy can be done by using several different processes. It can be converted into three main products, namely: chemical feedstock, transportation fuels and power/heat generation (McKendry, 2002).

Briquetting is the widely known and commonly spread technology in compacting the materials. The technology uses chemical properties and mechanical properties of materials to compress them into compacted shape (briquettes) with and without usage of additives or binders in the high-pressure compacting process. Briquetting is mostly used in compacting the biomass (wood shavings, rice straw, bark, sawdust, cotton, paper, etc.). The biomass undertakes the process of briquetting, while temperature and high pressure instantaneously act upon the mass, the cellular structures within the material release lignin, which binds individual particles into a compacted briquette unit. However, briquetting can also be used for compacting of compounded such as plastic waste or municipal waste for different purposes. Briquetting is performed by briquetting presses. The material loaded in the machine then it is pressed into the pressing chamber with high compacting pressure and high pressing temperature (Kers et al., 2010).

The general objective of the study was to evaluate and analyse the coffee husk and coco peat briquettes as biomass fuel. Specifically, the study aimed to: produce biomass briquettes of coffee husk, coco peat and their mixture; determine the calorific value of each type of biomass briquette; determine fixed carbon, volatile matter, ash content and moisture content of the different biomass briquettes; determine the ignition rate and burning rate of each type of briquette and the number of briquettes needed to boil 1L of water; determine the strength of the biomass briquettes; and compare each of the observed data for the three types of briquettes.

Materials and Methods

The study focused mainly on the evaluation and analysis of the calorific values, burning rate, ignition rate, volatile matter, fixed carbon, ash and moisture contents of the biomass briquettes made of coffee husk, coco peat, and their mixture as well as the number of briquettes needed to boil 1L of water and the strength of the briquettes. The study includes various processes in order to obtain the necessary data based from the objectives. These processes included biomass collection, biomass drying, grinding, binder preparation and mixing, briquetting, testing and analysis.

Materials and Equipment

The materials and equipment that were used in the study are the following coffee husk, coco peat, cassava flour, water, weighing scale, digital top loading balance, stopwatch, cooking pot, briquette press, laboratory thermometer, thermal camera and oxygen bomb calorimeter.

Collection of Biomass and Drying

Coffee husks were collected from Amadeo and Silang, Cavite, Philippines. The coco peat was gathered from Silang, Cavite, Philippines. The coffee husks and coco peat were sundried for 2-3 days to reduce and remove the moisture from the biomass. Desirable moisture range of biomass material used for briquetting is 8% to 12% (Bhattacharya et al., 2002). The lost excess energy is when moisture of biomass is more than 12% due to vaporise surplus moisture. On the other hand, totally dried biomass cannot be densified. Since, the heat is transfer with water molecule through the waste medium during the briquetting process. Drying is a requirement in briquetting of crop residues even though it entails additional cost in the process. Sun drying is the easiest and cheapest in drying biomass. The result was a reduction in the weight of the biomass. The dried end products were then pulverized into particles size distribution ranging from 1.0-3.0 mm (Bandara, 2018).

Binder Preparation and Mixing

Cassava flour was used as binding material for the briquetting. The cassava flour to water ratio was 1:10 while the biomass to binder ratio was 4:1 and then heating the mixture at 65°C. The mixture of cassava flour and water was heated for 10 minutes (min) to form a sticky consistency and the solution became transparent. The mixture was stirred continuously during gel preparation to prevent clump formation. The mixture was then added and mixed with the dried biomass. This process enhanced powder adhesion.

Briquetting

The biomass and the mixture with binder were made into briquettes using a briquette press. For the mechanical operation, the biomass and mixture were loaded directly into the briquetting moulder to form uniform-sized cylindrical briquettes. Each briquette has a diameter of 3.8cm with 1.2cm hole at the middle and a height of 4.8cm. The three types of briquettes as to composition were produced for the treatments. Using a briquette press, briquetting was done in Silang, Cavite, Philippines. The briquettes produced were sundried for one (1) week until the required moisture content was attained.

Testing and Evaluation

The briquettes were brought to the Forest Products Research and Development Institute (FPRDI) of the Department of Science and Technology (DOST) in Laguna, Philippines for the testing of the calorific value, volatile matter, fixed carbon, moisture and ash contents of coffee husk biomass briquettes, coco peat biomass briquettes and briquettes out of their mixture.

Compression Tests

The compression test of the briquettes as a measure of strength was also done in FPRDI. The two types of compression tests were done. The samples were placed on the equipment parallel to its length and the other set-up was done perpendicular to the length of each briquette. Since the cocopeat briquettes were not subjected to failure because the force only keeps on increasing and a breakage seemed impossible, only the force and stress at 10mm of each type of briquette were taken for comparison. The maximum force was taken perpendicular to the length of each cylindrical briquette. This kind of test was often done to test how much force the briquettes can withstand for the packaging.

Water Boiling Test

Prior to the final testing and evaluation, various preliminary tests were done to determine how many briquettes of each type were actually needed to boil 1 liter (L) of water. Water boiling test was conducted by boiling one liter of water with a specific number of each type of briquette samples using a charcoal stove to compare the fuel combustibility. Preliminary tests were done to determine the number of briquettes needed to boil 1L of water. The temperature reading of the water was taken after every five minutes using a laboratory thermometer (Onuegbu et al., 2011) until the water started to boil. On the other hand, the temperature reading of the briquettes during the test was also taken using a thermal camera. Specific fuel consumption during the water boiling test was calculated using equation (1).

$$SFC = M_{fc} / M_{bw} \qquad (1)$$

where: SFC = Specific fuel consumption, kg/li
M_{fc} = Mass of fuel consumed, kg
M_{bw} = Total mass of boiling water, li

Ignition rate

The ignition rate was determined as reported (Oladeji, 2010). Each sample was ignited at the bottom and allowed to burn until it completely turned to ash. A timer was used to record the time it took for each briquette to give the first spark and burn completely. The rate at which flame started was calculated by dividing the distance burnt by the time taken in seconds as shown in equation (2).

$$I_r = D_b / T_{tk} \qquad (2)$$

where: I_r = Ignition rate, mm/s
D_b = Distance burnt, mm
T_{tk} = Total time taken, s

Burning rate

The burning rates of briquettes were determined by recording the briquettes' initial weight before combustion and after the briquettes were burnt completely, the rate at which the fire consume the briquette samples were calculated using equation (3) (Onuegbu et al., 2011). The types of briquettes were then compared in terms of their calorific values, volatile matter, fixed carbon, moisture and ash contents, ignition rate, burning rate, number of briquettes needed to boil 1L of water, and strength of each briquette. The temperature of each type of briquette during the water boiling test was taken every minute using FLIR TG167 Spot Thermal Camera. During the water boiling test, water temperature was taken every five minutes using a laboratory thermometer

$$B_r = M_{tfc} / T_{tk} \qquad (3)$$

where: B_r = Burning rate, g/min
M_{tfc} = Mass of total fuel consumed, g
T_{tk} = Total time taken, min

Data Analysis

Completely Randomized Design (CRD) was utilized as an experimental design. Analysis of Variance (ANOVA- F test) was used for the statistical analysis of data. The significant differences among treatments' means were further analyzed using Duncan's Multiple Range Test (DMRT). The treatments were coffee husk, coco peat and a mixture consisting of 50% each of these two biomasses. Treatment 1 (T_1) was coffee husk, treatment 2 (T_2) was coco peat and a mixture consisting of 50% each of these two biomasses was treatment 3 (T_3). These treatments were replicated three times for a total of nine experimental units. Each treatment used cassava starch as binder. The dependent variables were the output data of this study. These were the calorific value, moisture content, volatile matter, fixed carbon, ash content, ignition rate, burning rate, number of briquettes needed to boil water, and strength of each briquette. The independent variables are the different types of briquettes. Proximate analysis of the produced briquettes involved the use of simple tests that focused on estimating the main constituents of biomass which had a direct influence on the combustion characteristics such as moisture content, amount of volatile matter, fixed carbon, and amount of ash. The calorific value of each briquette was determined using an oxygen bomb calorimeter. The strength of the briquettes was examined through the compression test.

Results and Discussions

Calorific Values

The results of study on calorific values found that coffee husk briquette (T_1) has the highest calorific value with 3,919.36 cal/g, followed by cocopeat briquette (T_2) with 3,910.19 cal/g and the briquette with the least calorific value among the three types is the mixture of both (T_3) with 3,864.22 cal/g. The results of analysis revealed that there were no significant differences among the three treatments when it comes to calorific values since their significance level was determined at 0.121. This means that the types of biomasses used did not affect the calorific values of the briquettes produced.

The calorific value of coffee husk, cocopeat and their mixture were comparable to the calorific value of coir dust 4120 kcal/kg and rice husk 3040 kcal/kg briquettes and briquettes blended with different coir dust and rice husk varied from 3757 to 4879 kcal/kg (Islam et al., 2014). The results indicated that the calorific value of the briquette depends on the calorific value of raw material and the density of the briquettes. The calorific value is an important property of biomass briquettes as it produces the energy content of the fuel (Aina et al., 2009). Calorific value of biomass as fuel also depends on its chemical composition and moisture content (Akowuah et al., 2012). Heating values determine the energy content of a biomass material. Is the property of biomass fuel that depends on the moisture content (Santhebennur and Jogttappan, 2012). The table 1 shows calorific value of the three types of briquettes used in this study.

Table 1. Calorific values of briquettes

TREATMENT	CALORIFIC VALUE (cal/g)			
	R_1	R_2	R_3	Mean
T_1	3,920.75	3,916.16	3,921.17	3,919.36
T_2	3,878.89	3,946.26	3,905.41	3,910.19
T_3	3,872.37	3,896.89	3,823.39	3,864.22

Proximate Chemical Analysis

The proximate chemical analysis included testing of ash content, moisture content, fixed carbon content, and volatile combustible matter.

Ash Content

The results of test on ash content found that T_1 had the highest with 7.76% followed by T_3 with 7.15% and T_2 had the least amount of ash content with 5.79%. Ash usually results from the presence of mineral components, which are difficult to degrade during carbonization, and they remain in charcoal as an undesirable residue. The ash content of 3 types of biomass briquettes were comparable to the charcoal briquettes that varies from about 0.5% to more than 5% and least ash content (4.67%) of briquetted charcoals (Yoseph et al., 2017). It also depends on the type of biomass used in preparing the charcoal (FAO 1985). Moreover, it is also influenced by the binder quality used during preparation of briquette. As the binder mixture used for briquette increases, the ash content of the briquette has a higher possibility to increase. The content of ash also differs from briquette to briquette, that affects transfer of heat to the surface of the biomass fuel, and the diffusion of oxygen to the surface of fuel during charcoal combustion (Kim et al., 2001). All the briquettes tested in this study were comparable to ash contents recommended limits in international standards (FAO 1985) of carbonized biomass briquettes. The results of analysis on ash content revealed that the three treatments are significantly different from each other as shown in table 2. The results were further analyzed using Duncan Multiple Range Test (DMRT). This means that the type of biomass used affects the ash content of the produced briquettes.

Table 2. **Ash content**

TREATMENT	**ASH CONTENT (%)**			
	R_1	**R_2**	**R_3**	**Mean***
T_1	7.64	7.79	7.85	7.76 ^{a}
T_2	5.59	5.63	6.16	5.79 ^{b}
T_3	7.46	7.21	6.78	7.15 ^{c}

p-value = 0.000 *Means followed by the same letters are not significantly different at 0.05 level using DMRT

Moisture Content

The results of study on moisture content found that T_1 has the highest moisture content dry basis with 11.42%, followed by T_2 with 10.85% and T_3 with 10.45%. The results of analysis on moisture content showed that the three treatments had no significant differences. This means that the type of biomass used did not affect the moisture content of each briquette. In generally, the moisture content of the charcoal briquette is expected to be low because of the lower its moisture content the higher its burning power. The moisture content of 3 briquettes used in the study were not comparable to standard moisture content value of briquette which is less than 3.6% for British standard and less than 8% for Japan standards (Sudiana et al., 2013, Lestari et al., 2015). The table 3 shows the average moisture content of different briquettes.

Table 3. **Moisture content**

TREATMENT	**MOISTURE CONTENT (%, db.)**			
	R_1	**R_2**	**R_3**	**Mean**
T_1	11.47	11.25	11.55	11.42
T_2	11.96	10.42	10.17	10.85
T_3	10.85	10.35	10.14	10.45

Fixed Carbon Content

The results of study on fixed carbon content were shown in Table 4. The highest fixed carbon content was obtained from T_1 with 24.53%, followed by T_3 with 19.31% and T_2 with 17.28%. Analysis of results on fixed carbon content revealed significant difference among the treatments.

However, T_2 and T_3 are comparable but T_1 and T_2 are significantly different so as T_1 and T_3. This means that coffee husk had a different effect with coco peat and mixed biomass when it comes to fixed carbon content. However, if the biomass were carbonized before briquetting positive possibilities that all the type of biomass briquettes will pass the standards. Hence the fixed carbon content of charcoal (charcoal consists mainly of carbon) ranges from a low of about 50% to a high of around 95% (FAO 1985).

Table 4. Fixed carbon content

TREATMENT	FIXED CARBON (%)			
	R_1	R_2	R_3	Mean*
T_1	25.37	24.34	23.88	24.53 ^{a}
T_2	18.19	20.08	13.56	17.28 ^{b}
T_3	18.98	19.78	19.16	19.31 ^{b}

p-value = 0.011 *Means followed by the same letters are not significantly different at 0.05 level using DMR

Volatile Matter

The results of test on volatile matter of 3 types of briquettes were presented in Table 5. The results found that T_2 had highest volatile combustible matter with 76.93%, the second was T_3 with 73.55% and lastly, T_1 with 67.70%. Volatile matter characterizes the components of carbon, hydrogen, and oxygen present in the biomass. Once it is heated, vapor holding a mixture of short and the long chain hydrocarbons will be released. Reports indicated that the content of volatile matter influenced the thermal performance of briquettes, the structure, and bonding within the briquette (Loo and Koppejan 2008). For example, the dung has low volatile content, resulting in flaming combustion (De Souza and Sandberg 2004). The results of analysis revealed highly significant difference among the treatments. Further analysis showed that T_2 and T_3 are comparable whereas T_1 showed significant difference from the other two treatments. This means that coffee husk had different effect with coco peat and mixed biomass when it comes to volatile combustible matter. The volatile matter of the 3 briquettes were far higher than the briquette charcoal volatile matter that varies from 40% to 5% or less (FAO 1985). May be this due to characteristics of biomass, as report indicated (Oliveira 1990), in wood a high level of lignin and a low level of extractives may results in lower levels of volatiles in charcoal briquette. Charcoals briquette with high volatile matters can be easily ignited, but may burn with a smoky flame, while low-volatile charcoal is hard to light, but it burns very clean. So, the production and uses of briquette depends on the type or purpose.

Table 5. Volatile matter

TREATMENT	VOLATILE MATTER (%)			
	R_1	R_2	R_3	Mean*
T_1	66.98	67.87	68.26	67.70 ^{a}
T_2	76.22	74.29	80.28	76.93 ^{b}
T_3	73.57	73.01	74.06	73.55 ^{b}

p-value = 0.002 *Means followed by the same letters are not significantly different at 0.05 level using DMRT

Strength of Briquettes

Force at 10 mm

Compressive strength, defined as the maximum crushing load a briquette could withstand before cracking or breaking (Rajkumar et al., 2013). It can be estimated from the maximum force applied to area of the face of briquette The table 6 shows the results of test on force at 10 mm. The results found that T_2 had the highest force at an average of 53.7493 kgf followed by T_3 with 47.1095 kgf and T_1 with 28.1095 kgf. The analysis of results revealed highly significant differences among the treatments. This means that the type of biomass used affects the strength of each produced briquette.

The briquettes in the were comparable to the strength possess by briquettes reported (Andres, 2016) with 0.24 kPa and 1.13 kPa for briquettes from carbonized rice hull and corncob respectively. The biomass briquettes in this study exceeds the strength as reported by (Sen, et al., 2016) briquettes with molasses as binder at the ratio of 6:4 yielded maximum compressive strength (14.94 kg/cm^2)) followed by the briquettes using the starch gel (13.82 kg/cm^2)) and concentrated slop (11.53 kg/cm^2) as the binders at ratio of 6:4. Briquettes from soybean residue and cassava pulp binder showed lower compressive strength ranging from 0.61–2.31 and 0.37–1.13 kg/cm^2, respectively. The results might be due to the nature of the biomass and methods used in producing the briquettes. The variations in the particle size, the mixing ratio and compaction pressure have considerably influenced the compressive strength. Material with higher density was more likely to possess higher ultimate stress than that of lower density as reported (Jamradloedluk et al., 2010). The compressive strength of the produced briquettes increased with the decrease in particle size. The compaction pressure is another considerable factor that contributes to the strength properties. It can be attributed to the pressure applied to achieve the compactness that enhances the inter-molecular bonding property of the briquette particles, hence improves the strength property. Compressive strength also increases the durability of briquettes by decreasing the moisture absorbing capacity which deteriorates the longevity of briquettes (Kers et al., 2010).

Table 6. Force at 10 mm, measured parallel to the length

TREATMENT	FORCE AT 10 mm (kgf)			
	R_1	R_2	R_3	Mean*
T_1	28.62	27.68	28.03	31.11^a
T_2	50.88	55.86	54.50	53.75 ^{b}
T_3	47.36	46.67	47.29	47.11 ^{c}

p-value = 0.000 *Means followed by the same letters are not significantly different at 0.05 level using DMRT

Stress at 10 mm

The results of study on stress were shown in table 7. The T_2 had the highest stress with a value of 0.05579 kg/mm^2 followed by T_3 with 0.04633 kg/mm^2 and T_1 with 0.03120 kg/mm^2. The results of analysis on stress revealed that all treatments were significantly different from one another. The same with the results of force at 10 mm, the type of biomass affected the stress of briquette produced.

Table 7. **Stress at 10 mm, measured parallel to the length**

TREATMENT	STRESS AT 10 mm (kgf/mm^2)			
	R_1	R_2	R_3	Mean*
T_1	0.033	0.030	0.032	0.031^a
T_2	0.049	0.055	0.064	0.056^b
T_3	0.046	0.046	0.047	0.046^c

p-value = 0.001 *Means followed by the same letters are not significantly different at 0.05 level using DMRT

Maximum Force

The results of test on maximum force were presented in table 8. It shows that among the three treatments, T_2 had the highest value with 22.864 kgf. This was followed by T_3 with 14.3904 kgf and T_1 with 8.4719 kgf, the least value out of the three. The analysis of results revealed that all the three treatments were significantly different from each other. This means that the type of biomass used largely affected the strength of the briquettes produced.

Table 8. **Maximum force, measured parallel to the length**

TREATMENT	MAXIMUM FORCE (kgf))			
	R_1	R_2	R_3	Mean*
T_1	8.12	8.43	8.86	8.47^a
T_2	23.70	22.58	22.31	22.86^b
T_3	14.84	14.09	14.24	14.39^c

p-value = 0.000 *Means followed by the same letters are not significantly different at 0.05 level using DMRT

Characteristics of Briquettes in Boiling the Water

Burning Rate

As shown on Table 9, the T_2 had the highest burning rate with 8.6311 g/min, followed by T_3 with 8.5913 g/min and T_1 with 6.6110 g/min. The results of analysis revealed that T_1 was significantly different from the other two treatments. This means that coffee husk had different characteristics compared with coco peat and mixed biomass when it comes to burning rate. The average burning values of biomass briquettes produced were comparable to the burning rate reported by (Oyelaran et al., 2015) with average burning rates 0.587 kg/hr with 20% binder, 0.661 kg/hr with 15% binder, 0.792 kg/hr with 10% binder, 0.881 kg/hr with 5% binder. The observation attributed to the porosity that exhibited between inter and intra particles which enable easy infiltration of oxygen and out flow of combustion briquettes as reported (Chin, et al., 2000, Jindaporn, et al., 2005). Furthermore, based of the report, the finer particle size based on the combustion tests might be attributed to lower porosities and this hindered mass transfer, such as drying, devolatilization and charcoal burning processes, due to fewer free spaces for mass diffusion. Consequently, its burning rates (Briquette weight reduction rates) might be reduced. The present study indicated that the burning rate of the briquettes increased with increase in particle sizes (Chin et al., 2000, Jindaporn et al., 2005).

Table 9. Burning Rate

TREATMENT	BURNING RATE (g/min)			
	R_1	R_2	R_3	Mean*
T_1	6.445	6.588	6.800	6.611^a
T_2	8.624	8.550	8.719	8.631^b
T_3	8.440	8.555	8.779	8.591^b

p-value = 0.000 *Means followed by the same letters are not significantly different at 0.05 level using DMRT

Specific Fuel Consumption

The results of test on specific fuel consumption were presented in Table 10. This shows that T_3 had the highest with 0.2921 kg/li, followed by T_2 with 0.2158 kg/li and T_1 with an average value of 0.2116 kg/li. Analysis of results revealed highly significant differences among the treatments. However, T_1 and T_2 are comparable but T_1 and T_3 were significantly different and T_2 and T_3 as well. This means that coffee husk and coco peat had different effect with mixed biomass when it comes to specific fuel consumption. The average specific fuel consumption values of all biomass briquettes in this study can be compared to the performance average specific fuel consumption of the briquettes with 20% binder with 0.067, 15% binder with 0.103 J/g, 10% binder with 0.128 J/g and 5% binder briquettes with 0.267 J/g as reported (Oyelaran et al., 2015).

Table 10. Specific Fuel Consumption

TREATMENT	SPECIFIC FUEL CONSUMPTION (kg/liter)			
	R_1	R_2	R_3	Mean*
T_1	0.200	0.217	0.218	0.212^a
T_2	0.216	0.205	0.227	0.216^a
T_3	0.295	0.282	0.299	0.292^b

p-value = 0.000 *Means followed by the same letters are not significantly different at 0.05 level using DMRT

Number of Briquettes to Boil 1 L of Water

The table 11 shows that T_3 had the highest number of briquettes needed to boil 1 liter of water with a mean value of 24.67 pieces (pcs), followed by T_2 with 23 pcs, and T_1 with 11.67 pcs. The analysis of results showed that all three treatments were significantly different from each other. This means that the type of biomass used affects the number of briquettes needed to boil 1L of water for each type of briquette.

Table 11. No. of briquettes needed to boil 1 L of water

TREATMENT	NUMBER OF BRIQUETTES (pcs)			
	R_1	R_2	R_3	Mean*
T_1	11	12	12	11.67^a
T_2	23	22	24	23.00^b
T_3	25	24	25	24.67^c

p-value = 0.000 *Means followed by the same letters are not significantly different at 0.05 level using DMRT

Ignition Rate

The ignition time is time required by the briquette for starting to flame. It determines how the briquette is combustible. The results of test on ignition rate were presented in table 12. It shows that T_2 had the fastest ignition rate with 0.03130 mm/s, followed by T_3 with 0.02484 mm/s and T_1 with 0.01338 mm/s. The result of analysis of revealed that all three treatments were significantly different from each other. This means that the type of biomass used affects the ignition rate of each produced briquette. The ignition time is usually varied from 5 min to 10 min. The ignition time may result to decreased with the increased the in mixture of binders (Lestari et al., 2017). The ignition time is the function of the volatile matter. The higher level of volatile matter indicated that fuel will be ignited easily and flame length increase (Elinge et al., 2011). Briquettes with a good ignition rate have a better thermal efficiency and with lesser environmental hazard (Praveena et al., 2014).

Table 12. Ignition rate

TREATMENT	IGNITION RATE (mm/s)			
	R_1	R_2	R_3	Mean*
T_1	0.013	0.013	0.013	0.013^a
T_2	0.028	0.033	0.033	0.031^b

TREATMENT	IGNITION RATE (mm/s)			
	R_1	R_2	R_3	Mean*
T_3	0.025	0.025	0.025	0.025^c

p-value = 0.000 *Means followed by the same letters are not significantly different at 0.05 level using DMRT

Briquette Temperature

Briquettes temperature was the recorded temperature in a duration of time. The figure 1 shows the average briquette temperatures for the three treatments of water boiling test. It took an average of 10.67min for the coffee husk briquettes (T_1) to reach the maximum temperature reading of 376.95°C, it was measured using the thermal camera, followed by coco peat briquettes (T_2) with an average of 12min and a reading of 358.4°C and 13.67min for mixed briquettes (T_3) with temperature of 373.3 °C.

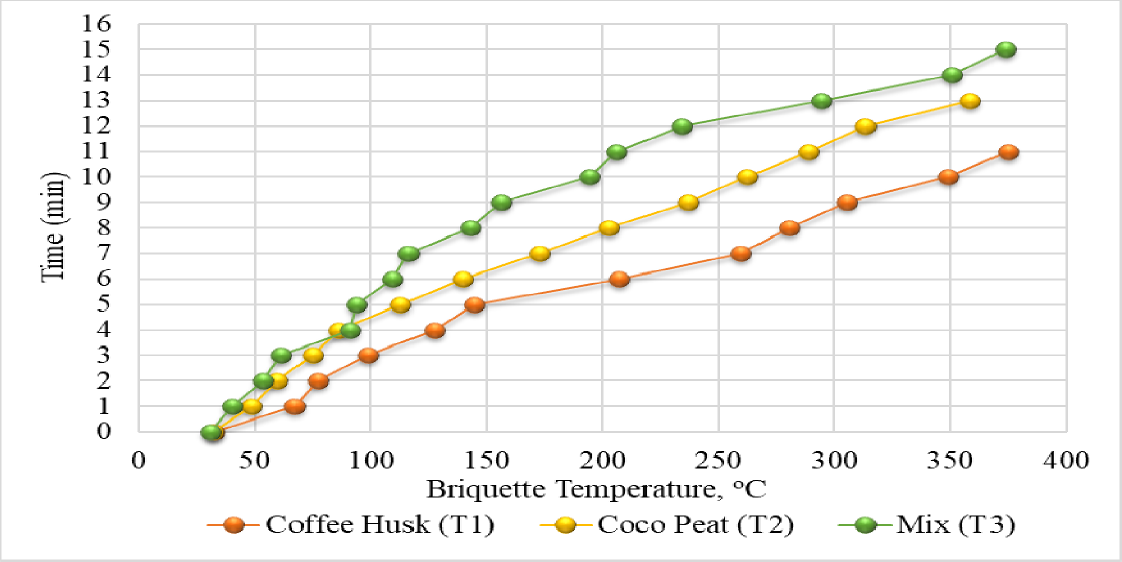

Figure 1. Briquette temperatures (°C)

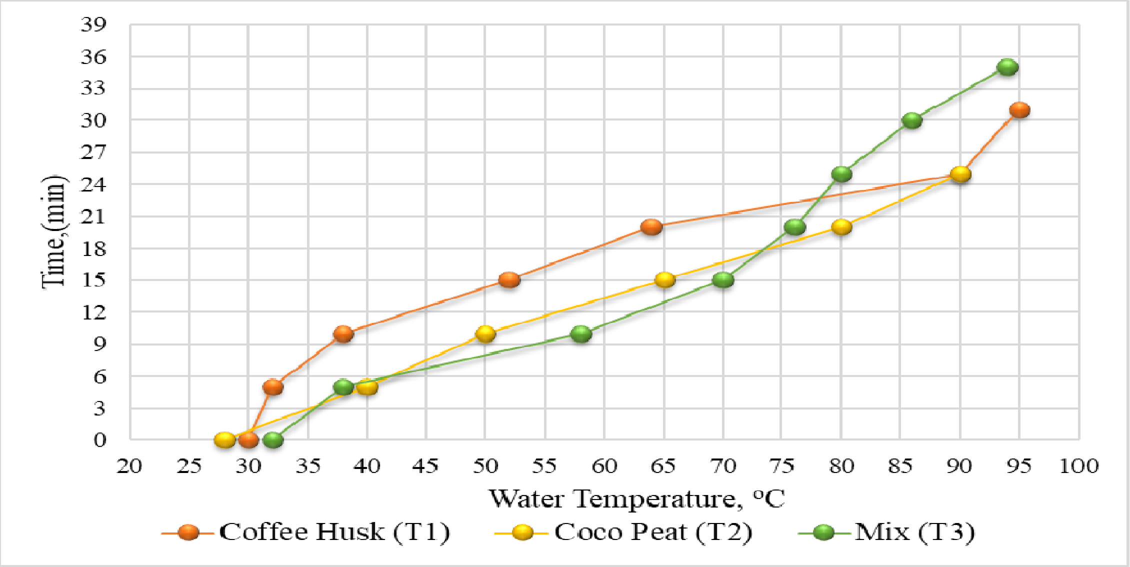

Figure 2. Average water temperature every 5 minutes.

Boiling of Water

The test for the boiling of water was the recorded water temperature in a time interval. The results of test on water boiling were presented figure 2. The results found that coco peat briquettes had the fastest time with an average of 25min at 95 ^{o}C to start the boiling of 1 liter water. Meanwhile, it took an average of 32min for the water to boil at 95.5 ^{o}C using the briquettes made of coffee husks. Lastly, using mixed briquettes, that took 34min at 95.0 ^{o}C to boil water.

Conclusion

The study was conducted to evaluate and analyse the coffee husk and cocopeat briquettes as biomass fuel. Specifically, the study aimed to: produce biomass briquettes of coffee husk, cocopeat and their mixture; determine the calorific value of each type of biomass briquette; determine fixed carbon, volatile matter, ash content and moisture content of the different biomass briquettes; determine the ignition rate and burning rate of each type of briquette and the number of briquettes needed to boil 1L of water; determine the strength of the biomass briquettes; and compare each of the observed data for the three types of briquettes. The study used 3 treatments and the tests and analysis were made in the laboratory. Three types of briquettes were produced composed mainly of coffee husks, coco peat, and a mixture of both. The briquettes were brought to the Forest Products Research and Development Institute (FPRDI) of the Department of Science and Technology (DOST) in Laguna for the testing of the calorific value, volatile matter, fixed carbon, moisture and ash contents, as well as strength of coffee husk biomass briquettes, coco peat biomass briquettes and briquettes out of their mixture. Water boiling tests were done by the researcher. Briquette and water temperatures were also gathered using a thermal camera and a laboratory thermometer. Ignition and burning rates were also determined by the researcher. The results of the study showed that ash content, fixed carbon content, volatile matter, strength, burning rate, specific fuel consumption, number of briquettes needed to boil 1 liter of water and ignition rate revealed significant differences among the treatments while calorific values and moisture content showed no significant difference. Based from the results of the study, the following conclusions were made: coffee husk gives the best fuel properties among the 3 treatments in terms of calorific value, fixed carbon content, volatile matter, and burning rate; the least number of coffee husk briquettes were used to boil 1 liter of water; among the three treatments, coco peat briquettes endured the greatest amount of force thus the strongest and the briquettes made from the mixture of coffee husks and coco peat had the lowest moisture content.

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