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INVESTIGATION ON THERMAL CHARACTERISTIC OF BANANA WASTE/ WOOD SAWDUST BRIQUETTE

Abdul Mu'iz Abdul Razak[a], Amirul Asraff Abd Razak[a], Ku Zarina Ku Ahmad[a], Mohd Faizal Abdullah[a], Raja Nor Izawati Raja Othman[a]

[a] Department of Mechanical Engineering, Faculty of Engineering, National Defence University of Malaysia, Sungai Besi Camp, 57000 Kuala Lumpur, Malaysia

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ABSTRACT

Current consumption of fossil fuel has raised questions on related topics related to environmental concern and global warming which need to be minimized as per regulations in various countries. This has resulted in the development of various fossil fuel alternatives such as recycling biomass into energy sources to diversify energy supply. This study aims to produce solid fuel briquettes from sawdust and banana waste including pseudo-stem, leaves, and banana peel. This is to take advantage of the currently untapped and abundant resource of banana waste in the agriculture sector and timber industry. In this research, banana peel, molasses and starch are chosen as a binder for briquette production. This project aims to study the combustion characteristic of solid biomass briquette and optimize the control factor using Taguchi method. Based on Taguchi statistical analysis, the combustion characteristic is mainly influenced by banana waste ratio, sawdust ratio and sawdust ratio. Thermogravimetric analysis (TGA) done on the samples exhibited four major stages of mass losses with Briquette 1 consisting of 30% banana peel binder, 0:1 Banana stem: Banana leaves ratio and 10 % sawdust weight possessing the least mass residue. This combustion analysis gave four parameters which were ash content (3.0–11.0 %), volatile matter (89.0–97.0 %), moisture content (16.5–44.0 %) and dry matter basis (56 - 83.5 %) where some of the briquette sample falls within the standard range of ISO 17225-1:2020. Based on experimental results the binder ratio exhibited the most contribution to all combustion properties. To minimize ash content and maximize volatile matter the type of binders is the least significant factor. However, the banana waste ratio is the least significant factor in minimizing moisture content.

1.0 INTRODUCTION

Energy is a vital element in daily life with application ranging from industrial uses to warming the body. However, to combat energy issues which is dwindling fossil fuel supply, industrial carbon footprint, climate change and shift in energy prices focus have turned towards renewable energy [1]. Malaysia possesses an abundance of usable biodiversity which could be utilized for generation of renewable energy such as solar, wind power, hydroelectric and biomass but these resources are not fully utilized due to lack of knowledge from the government or public. One of the sustainable energy sources available is biomass which presents the benefit of reducing carbon emission and the briquetting process is one of the processes used to convert biomass into useable energy [2]. This process has been performed in Malaysia using palm kernel expeller (PKE) and empty fruit bunches (EFB) waste from palm oil sector and utilizing screw extrusion technology to densify the waste into briquettes at high temperature and pressure.

*Corresponding Author | Ku Ahmad, K. Z. | kuzarina@upnm.edu.my

The benefits of such method include availability throughout the year, reduced cost, high calorific value, longer burning period and environmental friendliness. One of the most commonly available agriculture wastes in Malaysia is banana which produce waste in the form of leaves and stems of the tree after harvest and the discarded peel after the fruit is consumed. Conversion of the waste into energy have been attempted in multiple experiments among them using only banana waste and composite briquettes with rice husk [3-4]. According to Abdullah et al., (2013), banana is Malaysia's second most widely grown fruit covering 26,000 hectares of farmland with annual production of 530,000 metric tons [5]. Taking up to 10-12 months before harvest the tree only bears fruit once and cut down after the fruit is harvested producing an estimated four (4) tonnes of waste for every one (1) tonnes of fruit harvested and out of that amount 100 kg of fruit is rejected. At the ratio of four times the amount of waste banana waste is an attractive source of potential biomass for conversion into renewable energy in the form of thermal power or biogas.

In addition to banana waste sawdust is readily available in Malaysia since it is a common waste product from harvesting and processing of wood which may be a substantial source of pollution [6]. Composite briquettes utilizing sawdust and banana waste have been successfully produced in Malawi and sawdust composite briquettes produced with various biomass including straw pellets and cotton stalk [7-9]. The benefits of improved mechanical performance from the small particle size of sawdust proven by Zepeda-Cepeda et al., (2021) and it combustion performance as in Nazari et al., (2019) [4, 10]. As cited above, production of briquettes using banana waste and sawdust is possible using various mixtures and binders. However, to our knowledge there is no optimization in the production of these briquettes and the effects of each production parameters using Design of Experiment (DoE) method. This study aims to use Taguchi Method to determine the optimum control factor for combustion of banana waste and sawdust composite briquettes.

2.0 EXPERIMENT

To produce the briquette, binders are necessary to bind the biomass together for low pressure briquette production. Dried banana pseudo-stem and sawdust was purchased from industry vendors while banana leaves are obtained from local banana trees including those that were cut down and dried banana leaves. Dried pseudo-stem is cut into smaller pieces before being blended in an electric blender. The leaves were placed in an oven at temperature of 70 ^{0}C for 24 hours before the dehydrated leaves are cut into smaller pieces and blended into particles small enough to be filtered using 2 mm sieve. To bind the materials, three binders were selected which is banana peel, molasses, and starch. Banana peel was obtained from local fruit vendors and cut into smaller pieces before blending. Molasses was purchased from local vendor and starch is obtained by mixing tapioca flour with water at 1:2 ratio of flour to water to produce a starch glue.

2.1 Experimental Design By Taguchi Method

The design of experiments (DOE) method provides optimization with a smaller number of experiments compared to factorial method by utilizing the analysis of variance and mean to analyse the result and interaction between factor effects. In this study the orthogonal array chosen is the 9-trial experimental (L9) with 4 factors chosen which is type of binders, binder ratio, banana waste ratio and sawdust weight. All independent factors were considered for three levels as done by Musabbikhah & Bakri, (2020) that used three levels of drying temperature, pyrolysis temperature, holding time and particle size. Another experiments done by Agomuo et al., (2019) used three levels of particle size, mixing ratio and compaction pressure that resulted in the 4 factors with 3 levels chosen for this study shown in Table 1 [11-12]. Binder selection was based on literature reviews on previous research done including molasses and starch by Anatasya et al., (2019) and banana peel done by Hite & Smith, (2011) and considering the availability of local binders [13-14].

Table 1. Parameters and their variation levels

Parameter and symbol	Level		
	1	2	3
Type of Binders	Banana peel	Molasses	Starch
Binder ratio (wt %)	30	50	70
Banana waste ratio (stem : leaves)	0:1	1:0	1:1
Sawdust weight (wt %)	10	15	20

*Corresponding Author | Ku Ahmad, K. Z. | kuzarina@upnm.edu.my

2.2 Sample Preparation And Characterisation

First, to fabricate the briquette a mould was used to hold the mixture when applying pressure on it. Commercially available aluminium plates are cut using metal cutter and machined into a mould with dimension of 100 mm x 100mm x 40 mm. A hydraulic press was used to apply pressure on the mixture during briquetting process at 7MPa since prior study done by Agomuo1 et al., (2019) produced briquettes at 3 - 5 MPa [12].

The blended materials are prepared according to the mixture specified in Taguchi orthogonal array in Table 2 followed by the pressing process with all mixtures having a total weight of 100 g before pressing to ensure accuracy of weight ratio and to fit the mould. In order to reduce noise, the pressing time is fixed at five (5) minutes since holding time was shown to be a factor [11]. Once ejected from the mould the briquettes are dried in the oven at 60 ^{0}C for 48 hours to minimize moisture and stabilize internal strengths and combustion ability according to ISO 17225-1:2020 that suggested moisture content to be no higher than 10 % for biomass briquettes.

Table 2. Taguchi orthogonal array of designed experiments based on coded levels

Sample No.	Control Factors			
	Type of binders	Binder ratio (wt %)	Banana waste ratio (B. stem : B. Leaves)	Sawdust weight (wt %)
1	Banana peel	30.00	0:1	10.00
2	Banana peel	50.00	1:0	15.00
3	Banana peel	70.00	1:1	20.00
4	Molasses	30.00	1:0	20.00
5	Molasses	50.00	1:1	10.00
6	Molasses	70.00	0:1	15.00
7	Starch	30.00	1:1	15.00
8	Starch	50.00	0:1	20.00

3.0 RESULT AND DISCUSSION

The ash content, volatile matter, moisture content and dry matter basis were compared in this research to the values suggested by ISO 17225-1:2014 for solid wood fuel combustion properties as done by Thulu et al., (2016) for blended banana waste and sawdust briquettes [7]. As shown in Table 3 below some of the samples fall within the recommended values except for the moisture content.

Table 3. Comparison combustion characteristic of briquette sample

Briquette Sample	Percentage (%)			
	Ash Content	Volatile Matter	Moisture Content	Dry Matter Basis
1	11.00	89.00	19.00	81.00
2	4.33	95.67	19.00	81.00
3	3.33	96.67	36.50	63.50
4	8.00	92.00	16.50	83.50
5	5.00	95.00	18.50	81.50
6	8.33	91.67	25.00	75.00
7	9.00	91.00	16.50	83.50
8	4.00	96.00	17.50	82.50
9	3.00	97.00	44.00	56.00

Thermogravimetric analysis (TGA) was used to examine the thermal characteristics of banana waste sawdust briquettes shown in Figure 1 below. From the TGA results Briquette 1 exhibited lowest total percentage weight losses of 0.72 % at the highest combustion temperature while Briquette 7 exhibited the highest percentage of 62.25 %. However, briquette 3 and 4 exhibited weight residue limit at 500 ^{0}C and 430 ^{0}C indicating the mixture are less suited for use as solid fuel due to lack of thermal stability at high temperature. From the TGA graph briquette 1 exhibited property that is a suitable for use as solid fuel with acceptable thermal degradation temperature and acceptable levels of ash content and dry matter available for combustion based on Table 3 above.

*Corresponding Author | Ku Ahmad, K. Z. | kuzarina@upnm.edu.my

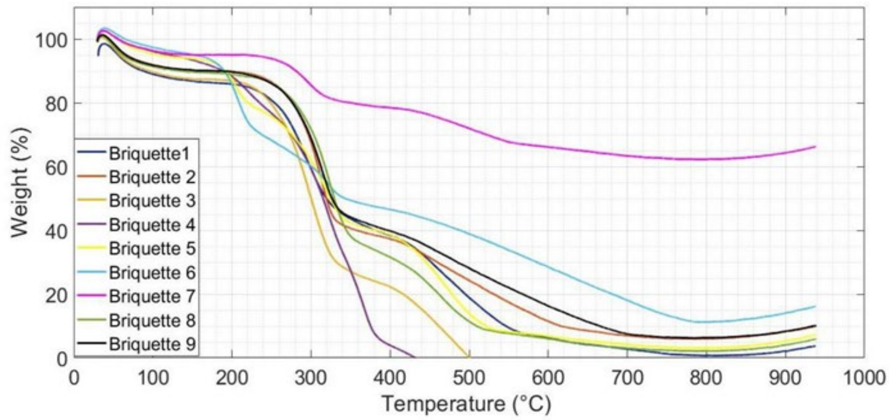

Figure 1. TGA curve of banana waste sawdust briquette

3.1 Pareto ANOVA

By using ANOVA and ANOM analysis, the significant factors and interaction of factors can be determined in the study. Determination of this criteria is based on the cumulative contribution ratio (expressed in %) of the control factors in the fabrication of the composite briquette shown in Figure 2 for combustion properties.

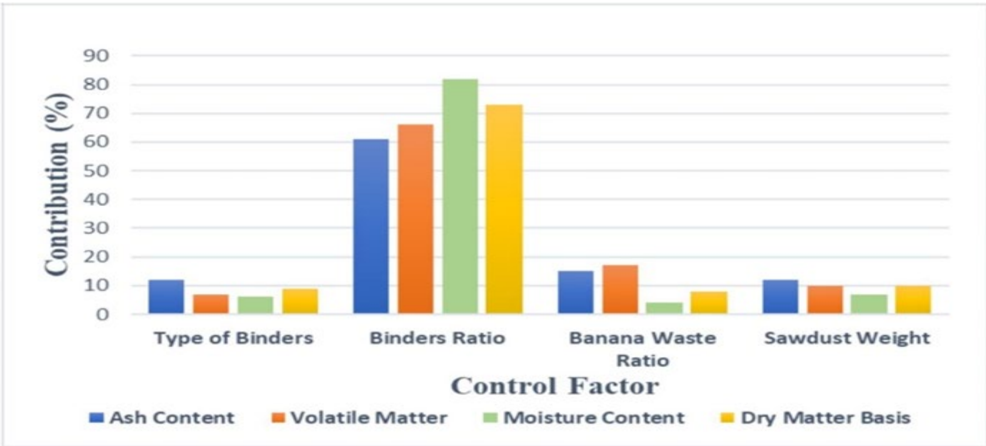

Figure 2. ANOVA diagram analysis of combustion properties

Based on Figure 2 above, to obtain the minimum ash content of banana waste sawdust briquettes, the binder ratio has dominant effects contributing 61 % as well as contributing the most for volatile matter, moisture content and dry matter basis at 66 %, 82 % and 73 % respectively. For ash content the type of binders is the least significant factor at 15 % as well as volatile matter at 7 %. However, for moisture content the banana waste ratio is least significant at 4 % as well for dry matter basis at 8 %.

3.2 Determination Of Optimum Conditions

The best possible levels of mix proportions were investigated based on the S/N chart for optimizing the combustion characteristics using Taguchi method. The effects of each parameter on the ash content, volatile matter, moisture content and dry matter basis is shown in Figure 3 to Figure 6 respectively. By analysing the maximum points for volatile matter and dry matter basis and minimum points for ash content and moisture content the optimum parameters are tabulated in Table 4.

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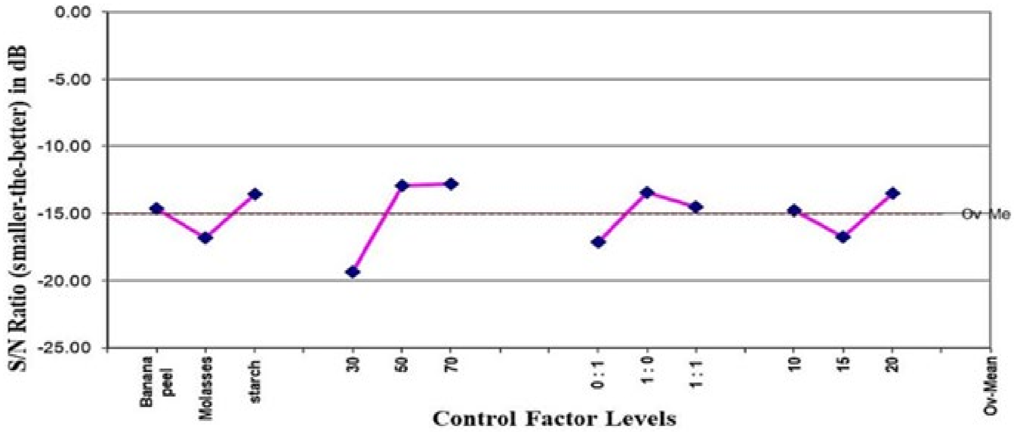

Figure 3. Factor effect plot for ash content

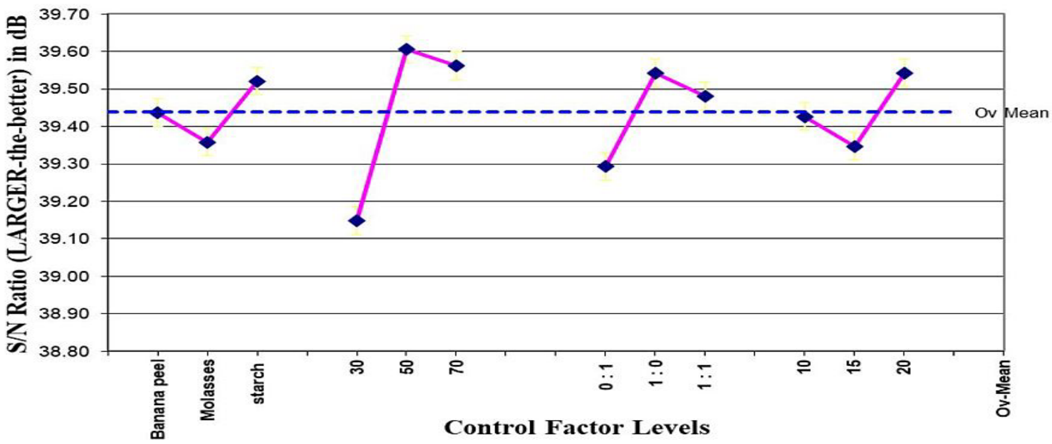

Figure 4. Factor effect plot for volatile matter

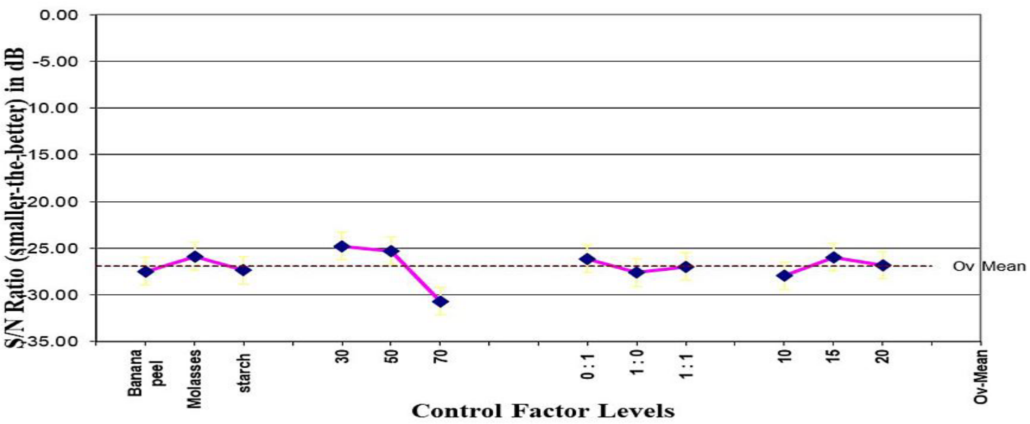

Figure 5. Factor effect plot for moisture content

*Corresponding Author | Ku Ahmad, K. Z. | kuzarina@upnm.edu.my

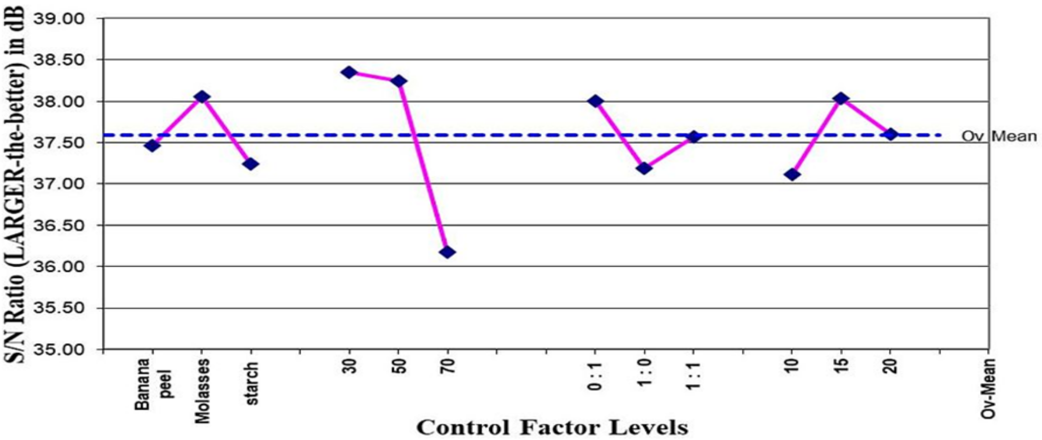

Figure 6. Factor effect plot for dry matter basis

Table 4. Optimum parameter for combustion properties of briquette

Optimum Parameter	Binders	Binders Ratio (weight%)	Banana Waste Ratio (Stem : Leaves)	Sawdust Weight (%)
Ash Content	Starch	70.00	1:0	20.00
Volatile Matter	Starch	50.00	1:0	20.00
Moisture Content	Molasses	30.00	0:1	15.00
Dry Matter Basis	Molasses	30.00	0:1	15.00

Based on the analysis of ANOVA and ANOM using Taguchi method also yield predicted value of ash content range of 10.9 - 11.1 %, volatile matter of 95.8 - 97.6 %, moisture content of 14.8 - 29.1 % and dry matter basis of 62.9 - 64.1 % for combustion characteristic. The higher amount of volatile matter in briquettes with increased amount of sawdust agrees with the results of Agomuo1 et al., (2019) due to the higher fixed carbon content [12]. The higher calorific value of sawdust with range of 28.78 - 30.26 MJ/kg depending of tree species enhanced the composite briquettes since banana waste exhibited lower energy density with banana leaves at 17.10 MJ/kg and pseudo-stem at 13.70 MJ/kg [15-16].

4.0 CONCLUSION

In this study, the Taguchi method was used to provide an optimized design with reduced number of experiments compared to factorial method. This method is found to be effective in providing optimized control factor for designing composite biomass briquettes where other biomass sources can be substituted according to locally available resources. From the experiments the binder ratio exhibited the most contribution to all combustion properties. To minimize ash content and maximize volatile matter the type of binders is the least significant factor. However, the banana waste ratio is the least significant factor in minimizing moisture content.

5.0 ACKNOWLEDGEMENT

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*Corresponding Author | Ku Ahmad, K. Z. | kuzarina@upnm.edu.my