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Investigating the effect of Mechanical force, Feedstock composition and Binder ratio on the energy content of Solid biomass Pellet fuel

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Abstract -Biomass has been the first type of fuel ever used as an energy source since the beginning of human civilization. Less valued biomass agricultural residues including rice husk, maize cob, coffee husk and saw dust are potentially available. One way of using these biomasses is through pellet densification by combining these biomasses with different composition and with help of binder and through the application of mechanical compressive force. The objective of this paper is to investigate the effect of the percentage feedstock composition, binder ratio and the amount of the applied compressive force on the energy efficiency of noncarbonated pellet. Starch has been used as a binder and extracted from cassava root tubes. The feedstock has been prepared in two levels of compositions; the first is by having equal composition of each feedstock and the rest feedstock by weight. To investigate the effect of mechanical force, three compressive forces has been used. The result demonstrated that applied pressure, feed composition and binder ratio have a significant effect on the physicochemical properties of the produced pellets. The caloric value of the pellet has increased with the change in application of compacting force. So we conclude that due to the Water Boiling Test (WBT) conducted to analyze the energy efficiency of the pellet fuel, pellets produced through the application of 180kN takes a minimum time to boil one liter of water with a minimum fuel consumption.

Index Terms- Applied pressure; Calorific value; Feedstock composition; Pellet; Solid biomass fuel.

1. Introduction

Biomass has been the first type of fuel ever used as an energy source since the beginning of human civilization. Biomass supplies 14% to the world's energy consumption and is still considered a key renewable energy resource of the future [1]. The sources of biomass are available in various forms such as plants, animal residues, crops, etc. Apart from providing food, biomass is also used for building materials, heating and cooking as one of the energy uses. It can be argued that the biomass fuels could potentially provide much more extensive source of energy if it is used in a sustainable way with efficient technologies.

Besides the efficiency improvements of available energy systems, there is a need to consider biomass residues which are left over from agricultural, forestry or industrial activities as a substantial biomass fuel.

Agricultural residues are, in principle, one of the most important of these.

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They arise in large volumes and in the rural areas. Agricultural residues which are freely available are often discarded or burned as wastes. They occur in large amounts and have the potential to be an important energy source for fuel production. The major residues are tiff straw, coffee husk, bagasse, wheat straw, and rice husk and maize cobs.

In order to make the biomass materials (agricultural residues) available for a variety of applications, the challenges with the use of biomass materials in their original form must be resolved. Because of its high moisture content, irregular shape and sizes, and low bulk density, biomass is very difficult to handle, transport, store, and utilize in its original form. One solution to these problems is densification of biomass materials. Densification is the process of compacting plant residues into a denser fuel product. The densified biomass can be converted in the form of pellets, briquettes, or cubes.

Pellets are solid fuels produced from un-carbonized solid wastes such as sawdust, wood chips, peat and agriculture waste (rice straws, wheat straws, cotton stalks, corn stalks, bagasse, fruit branches) by the process of densification. It is a way to convert loose biomass residues under a high pressure into high density solid blocks that can be used as a fuel.

The standard shape of a fuel pellet is cylindrical, with a diameter of 6 to 12 millimeters and a length of no more than 38 millimeters. Larger pellets are also occasionally manufactured; if they are more than 25 millimeters in diameter, they are usually referred to as “briquettes” [2].

This paper present the possible ways of increasing the energy value of the pellet products by having a ratio mixture of different agricultural feedstock and binding agent with the application of different mechanical force.

2. Methodology

Material: An agricultural residues including; rice husk, maize cobs, coffee husk and saw dust were the feedstock used to produce the pellet. Cassava flour which is extracted from cassava root tubers was used as a binding agent. A drying oven was used to measure moisture content of the sample. To reduce a particle size of the feedstock, maize cob was first chopped by hand and then subsequently ground using a disk grinder (Fritsch, Model No. D-55743, Idar-odserstein, Germany) but the other feedstock were introduced directly into the grinder since their particle size is convenient for grinding. Digital balance has been used to measure the mass of the sample during different test. A Nabertherm (Model No. Controller B180 MB2, Germany) muffle furnace was employed to test proximate analysis and ash content of pellet samples. The mixed feedstock material was pelleted using (DESC: ELE-Hoekcell, Model ADR 2000) compressive machine and also to test compressive strength of the produced pellet. A die and puncher were employed to produce the pellet.

The calorific value, or heat of combustion: is a measure of the energy available in the fuel. Knowledge of this value is essential in assessing the commercial worth of the fuel and to provide the basis of contact between producer and user (ASTM E711-87) [3]. Heating value is either expressed as low heating value (LHV) or high heating value (HHV). The calorific value can be determined using proximate analysis or adiabatic calorimeter.

Experimentally the sample of a pellet fuel calorific value can be measure by using Adiabatic bomb Calorimeter. The calorific value of pellet sample determined by using adiabatic bomb calorimeter from Geological survey. The temperature rise (change) of water within the inner vessel of the measuring cell has used by the calorimeter to calculate the calorific value of the pellet sample.

2.1 Experimental set-up

Experimental Setup comprised a grinder and a compression machine required for extruding the pellets from the die and punch. The dried rice and coffee husks was grounded to obtain the desired particle size of the raw biomass feedstock. Due to the size, maize cobs were first crash into small size to introduce into a grinder. Sawdust can be directly used since the parcel size can be used in pelleting. The grounded feed-stocks with different composition were then mixed with gelatinized cassava flour in order to make powder binder mixture. The dried cassava flour was gelatinized so as to improve the binding efficiency, and water and heat was used during the process. Then, the mixture was passed through extruder via the designed die. Finally, the produced pellets were kept in a dry atmosphere for further characterization of physicochemical properties of the pellet.

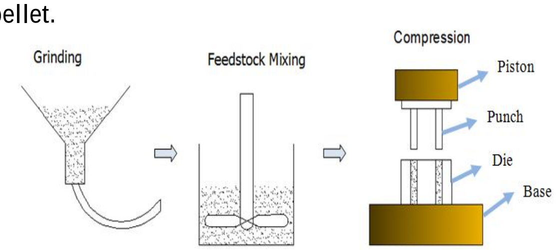

Fig. 1: Experimental set-up for un-carbonized pellet production

The experiment were designed to investigate the effect of operating parameters such as Compacting force (Pressure), Binding ratio, and Feedstock composition on the final product of pellet. As a result the physicochemical properties of the pellet were determined. In this study, the experiment was carried out in three level of compacting force, two level of binder ratio and two level of feedstock composition. The experimental design was employed based on factorial design for three factors at one in three levels and the other at two levels in order to identify the optimal parameter combination. Therefore; the combination of three factors of which each correlated as shown in Table 1.

Table 1:
Factorial combination of each factor for pellet testing

Run Order	Compacting Force (KN)	Binder Ratio (% by weight)	Feedstock Composition (% by weight)
1	120	6	25% each feedstock*
2	120	12	40% Saw dust 20% Rice husk 20% Maize Cob 20%Coffee husk
3	120	12	25% each feedstock*
4	120	6	40% Saw dust 20% Rice husk 20% Maize Cob 20% Coffee husk
5	150	6	25% each feedstock*
6	150	12	40% Saw dust 20% Rice husk 20% Maize Cob

			20% Coffee husk
7	150	12	25% each feedstock*
8	150	6	40% Saw dust 20% Rice husk 20% Maize Cob 20% Coffee husk
9	180	12	25% each feedstock*
10	180	6	40% Saw dust 20% Rice husk 20% Maize Cob 20% Coffee husk
11	180	12	25%each feedstock*
12	180	6	40% Saw dust 20% Rice husk 20% Maize Cob 20% Coffee husk

*Equal feedstock composition, i.e. saw dust, Rice husk Maize cob and Coffee husk.

3. Results and Discussions

The calorific value, or heat of combustion, is a measure of the energy available from a fuel. Knowledge of this value is essential in assessing the commercial worth of the fuel and to provide the basis of contact between producer and user [3]. The heating value of the pellet fuel samples is experimentally analyzed in Geological survey, Geoscience laboratory, and based to the result, table 2 presents the higher heating value of each pellet samples.

TABLE 2:
HIGHER HEATING VALUE OF PELLET SAMPLES

Source	Sum of Squares	df*	Mean Square	F Ratio	Sig. (p value)
Model	3.506E 8	12	29213015 .128	1120 88.5 60	.000
Feedstock	34339. 805	1	34339.80 5	131. 760	.000
Binder	1356.1 57	1	1356.157	5.20 3	.042
Compacting force	42623. 188	2	21311.59 4	81.7 71	.000
Feedstock * Binder	214.02 5	1	214.025	.821	.043
Feedstock * Comp. force	476.73 3	2	238.366	.915	.004
Binder * Comp. force	1780.6 09	2	890.305	3.41 6	.067
Feedstock * Binder * Comp. force	352.13 1	2	176.066	.676	.052
Error	3127.4 93	12	260.624		
Total	3.506E 8	24			

** In pellet sample, letters P, B, and F refers to pellet Compacting force (Pressure), Binder ratio, and Feedstock composition, respectively and their respective level: 1 indicates first level, 2 is second level and 3 is third level.*

- 1 is first level of pressure 120kN, 2 is second level 150kN, and 3 is third level 180kN.

- 1 is first level of binder ratio 6% and 2 is second level 12%.

- 1 is first level of feedstock composition: 25% of each feedstock i.e. saw dust 25%, Maize cob 25%, Rice husk 25% and Coffee husk 25%.

2 is second level of feedstock composition: 40% of saw dust and the rest is 20% i.e. Maize cob 20%, Rice husk 20% and Coffee husk 20%.

The heating value of pellet samples presented in table 2 ranges from 3727.91kcal/kg to 3928.54kcal/kg, almost having more than 100kcal/kg difference. And the maximum value, i.e. 3928.54kcal/kg, observed for a pellet produced from 40% of sawdust and the rest 20% feedstock with the addition of 6% binder and by applying 180kN compacting force. A minimum value of 3727.91kcal/kg has seen pellet having 25% each feedstock with 12% binder and by applying a 120kN compacting force. These values were favorably compared with Dwi Setyaningsih's [4] results, whose reported the calorific values of biomass pellet produced from three different feedstock sources by having them with different composition. According to their experimental result, the calorific value of pellet with a feedstock composition of 50% maize cob and 50% coffee husk, they found a calorific value of 4283.65 kcal/kg and for a feedstock composition of 50% bagasse, 25% peanut shell and 25% coffee husk, the calorific value is 4366.15 kcal/kg. With compared to these result, the calorific value found in these study has shown a higher energy value.

Table 3 shows ANOVA analysis of variables effects of a three-way ANOVA, whether either of the three independent variables, i.e. "Feedstock", "Binder" and "Compacting force" or their interaction are statistically significant or not on calorific value of pellet samples for a significance level of p=0.05 (95% confidence interval).

TABLE 3:
ANOVA ANALYSIS OF VARIABLES EFFECTS ON PELLET HHV

Run	Sample Variables*			HHV (kcal/kg)
	F	B	P	
1	1	1	1	3755.37
2	1	2	1	3727.91
3	2	1	1	3840.04
4	2	2	1	3824.16
5	1	1	2	3780.69
6	1	2	2	3764.93
7	2	1	2	3841.38
8	2	2	2	3840.23
9	1	1	3	3812.78
10	1	2	3	3840.48
11	2	1	3	3928.54
12	2	2	3	3915.93

Dependent Variable: Calorific Value, *df = degree of freedom

Table 3 presents feedstock composition and compacting force and their interaction has a statistically significant effect on the calorific value of the pellet fuel. Binder and the interaction between 'feedstock*binder' also has a statistical significance level of $p<0.05$, which means that both also has a significant effect on the calorific value of the produced pellet fuel. But the interactions between 'Binder*Compacting force' and 'Feedstock*Binder* Compacting force' have no statistically significance in the calorific value of the pellet. This means that on the calorific value of the produced pellet, the three independent variables (Feedstock, Binder and Compacting force) have s significant effect. And some of their interactions also have a considerable effect on the energy value of the pellet fuel.

3.1 Effect of Feedstock composition on the Heating value of pellet

The calorific value of biomass fuel usually highly depends on the type of feedstock used during the fuel production. Between the two feedstock compositions used in this study, there is a mean value of 75.68kcal/kg heating value difference observed.

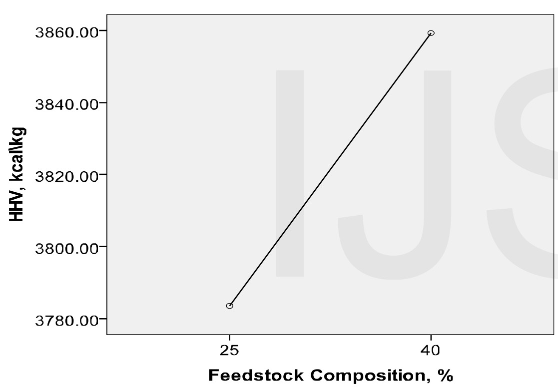

Fig. 2: Relation between Feedstock composition and Heating value

Fig. 2 shows the effect of different feedstock composition on the heating value of pellet fuel, and thus with the increasing amount of sawdust from the total feedstock composition, the heating value of pellet fuel also increases. It implies that the type of biomass used during pellet production has a significant impact on the energy content of the fuel. Dwi Setyaningsih [4] found out that by having two different feedstock with different composition, obtained a calorific value with a significant difference.

3.2 Effect of Compacting force on the Heating value of pellet

The amount of the applied compacting force in biomass densification process is crucial. Three compacting force levels have been employed in this study. Fig. 3 shows the effect of having different applied compacting forces in the calorific value of the produced pellet.

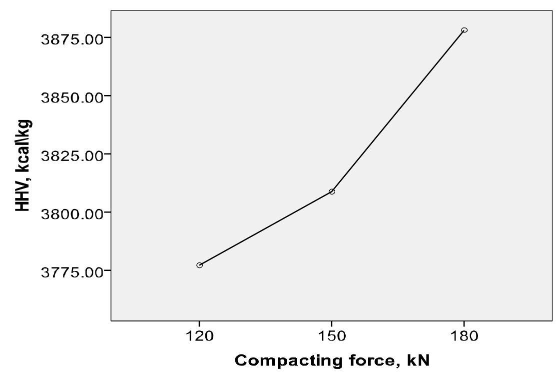

Fig. 3: Relation between compacting force levels and heating value

According to the graph, it shows that the calorific value of pellet is increased with the increasing applied compacting force. The increment shows a significant change in between compacting force of 150kN to 180kN. There is 31kcal/kg mean calorific value difference between 120kN and 150kN, and 69 kcal/kg mean value difference between 150kN and 180kN, according to table 4. Which indicates that, calorific value of the densified pellet fuel is highly related and shows a change to the applied mechanical force. For a fixed feedstock composition and binder ratio, the calorific value of pellet increased by almost more than 100kcal/kg difference, with increment of compressive force from 120kN to 180kN. The mean calorific value of pellet produced with the application of the three compacting force is presented in table 4. And the calorific value of pellet increased by a mean value of 100kcal/kg with the increasing mechanical force from 120kN to 180kN.

TABLE 4:

STATISTICAL DESCRIPTION OF COMPACTING FORCE ON CALORIFIC VALUE OF PELLET

Mechanical force	Mean calorific value	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
120kN	3777.261	5.708	3764.825	3789.697
150kN	3808.798	5.708	3796.361	3821.234
180kN	3878.152	5.708	3865.716	3890.589

Dependent Variable: Calorific Value

3.3 Effect of Binder on the Heating value of pellet

Binder in solid biomass fuel is usually added to help the densified fuel stay in shape and maintain its integrity. But it also helps to maximize the energy content of the fuel. In order to see this, fig. 4 presents the effect of having different binder ratio in the calorific value of the produced pellet.

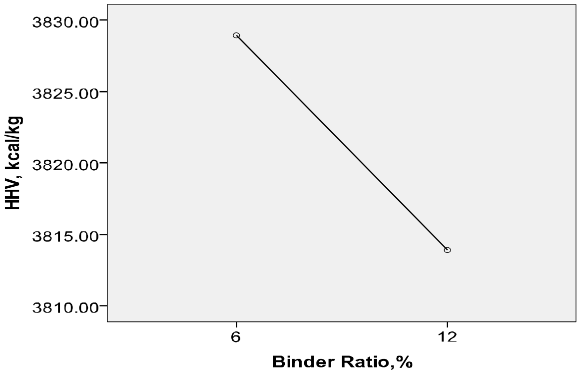

Fig. 4: Relation between Binder ratio and the Heating value of pellet

According to fig. 4, a heating value of pellet shows a change in between having a 6% and 12% (by weight) binder amount in the feedstock. Pellet produced with a 6% binder has a better energy value than that of 12%. This is because, instead of acting as a binder, the binding agent itself contains much percentage amount from the total composition, and that decreases the energy value of the pellet. Even though there is a difference in calorific value between this two binder levels, it is not that significant change as compare to the change in compacting force and feedstock composition.

4. Conclusions

In pellet fuel production, the amount of mechanical force applied, the percentage of binder added and the feedstock used and its composition shows a significant impact in the pellet stability and amount of heat released. With the fixed feedstock composition and binder ratio but by changing the applied compressive force from 120kN to 180kN, the heating value shows a change by 100kcal/kg between the two samples. The composition of feedstock used to produce a pellet is one of an important consideration. For sample pellet having the same compressive force and binder, but with different feedstock composition, the heating value is changes with an average heating value from 3783.577kcal/kg to 385.23kcal/kg. The change is by a mean value of 75.68kcal/kg of heat energy. Thus; heating value is highly dependent on the composition of the feedstock used on pellet production. With the increasing amount of sawdust composition, the heating value of the pellet increases as well. But samples having the same compressive force and feedstock composition, with the increasing binder amount by 6%, the heating value of pellet samples shows a decrement, and this is because instead of acting as a binder, the binding agent itself contains much percentage amount from the total composition and it decreases the heating value of the samples.

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