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Ironwood and mixed wood sawdust biopellet prototype innovation as an alternative energy of the future

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Abstract

Increased population growth causes the demand for fossil fuels to increase while the availability of these fuels is running low, so research needs to be done to find environmentally friendly alternative energy. Biopellet from a mixture of Ironwood and mixed wood (Meranti and Balsa) sawdust waste is one of the solutions in overcoming the energy crisis in the future. The objectives of this study were (1) to determine the biopellet characteristics from a mixture of Ironwood and mixed woods sawdust such as moisture content, density, volatile matter content, ash content, calorific value and fixed carbon content, (2) to identify the influencing factors in the manufacture of biopellet, (3) knowing the best quality of biopellet from various mixtures of raw material variations. This study used a completely randomized design with 5 treatments and 3 replications. The result of this study that the best biopellet characteristics were found in treatment B (70% of Ironwood + 30% Meranti and Balsa mixed wood sawdust waste) with moisture content value of 2.150%, a density of 0.773 g/cm^3, volatile matter of 68.450%, ash content of 1.204%, calorific value of 4,830.930 cal/g and fixed carbon value of 27.943%. Finding demonstrates that factors that influence the making of biopellet are the raw material and the processing process.

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Introduction

Indonesia's energy sector is experiencing serious problems, as the rate of domestic energy demand exceeds the growth in energy supply. Kerosene and fuel are imported, forcing our nation to seek alternative energy sources to overcome the fossil energy continuous demand from year to year. New and renewable energy (*Energi Baru dan Terbarukan* – "EBT") continues to be developed and optimized by changing the mindset that EBT is not just an alternative energy from fossil fuels, but should be a buffer in the national energy supply with an EBT portion of more than 17% by 2025 (Presidential Regulation No. 17 of 2006 on National Energy Policy) in the form of >5% biofuel, >5% geothermal, >% of other EBTs and 2% liquid coal, while other energy is still supplied such as >30% gas, >33% coal. The Government is committed to achieving the vision of 2025 to 2030, which is 25% EBT by 2030.

Indonesia has a potency of biomass waste that equals to 49,810 MW (bigger than the government power plants mega project target of 35,000 MW). However, only a very small amount of 1.618 MW or less than 4% that has been utilized (www.energibersama.com). One kilogram of wood pellet produces the same heat as half a liter of kerosene (Leaver, 2008).

Efendi (2007) stated that the total number of sawmills with license for utilization of timber (Izin Usaha Pemanfaatan Hasil Hutan Kayu – "IUPHHK") are 17 units, 283 units non-IUPHHK and 396 units are sawmill. According to the Forestry Service, in 2012 sawmill production in South Kalimantan has a production of 71, 777, 7592 m^3. According to Purwanto (2009), sawmill industries produce 40.48% waste consisting of 22.32% large wood piece, 9.39% small wood pieces and 8.77% sawdust. From the data, it can be imagined how big the waste generated from the sawmill industries which is left and thrown away. While on the other hand, we are experiencing an energy crisis, so the utilization of ironwood and mixed wood sawdust waste mixture become one of the solutions to solve the energy crisis.

Based on the above problem, research on biopellet from ironwood and mixed wood sawdust becomes very important considering the decrease of energy supply from fossil fuels, later, the information about the calorific value and other characteristics of the biopellet are expected to become the base of reference in developing the environmentally friendly future energy in the form of biopellet.

Materials and methods

The collection of ironwood and meranti+balsa sawdust was performed in the ironwood sawmill industries in Liang Anggang. The research method of making ironwood and meranti+balsa sawdust briquette was: materials were prepared, than Ironwood, Meranti and Balsa sawdust were carbonized. Raw materials were pounded until they became powder like. The tapioca flour was dissolved as much as 75 grams with 500 ml boiled water until it becomes a paste. Each sample was mixed with adhesive. The samples were fed into a press tool with diameter size (D) = 4.5 cm, height (T) = 7.5 cm. Samples were slowly removed from the press tool using wood. Finished briquettes were oven-dry at 200°C for 1 hour to reduce the moisture content Briquettes were ready for testing.

Test procedure

The physical characteristics of bio pelletwere measured using ASTM D5142-02:

Moisture content

The moisture content was determined by taking 1 gram of sample and placed it in a porcelain cup with known weights. The samples were oven-dried with temperature ±103°C for 24 hours until the moisture content is stabilized. Than, the samples were cooled in a desiccator until the temperature constant and then weighed, the moisture content is calculated by the formula:

Water content $= \frac{BB - BKT}{BKT} x 100\%$

Where:

BB= weight of materials before oven-dry

BKT= weight after oven-dry

Density

Density determination is expressed by the comparison between the weight and volume of the bio briquette. Testing was done using Archimedes method that is to measure the mass and volume of the test sample by submerging the sample into the water in a measuring cup. The density is calculated by the formula:

Density $= \frac{massa\ (g)}{volume\ (m3)}$

Ash content

The determination of ash content was carried out with 1 gram of sample placed in a porcelain cup whose weight is already known. The samples then put into the oven with temperature 600-900℃ for 5-6 hours. They were further cooled in the desiccator until they're stable and weighed. The ash content is calculated using the formula:

Ash content $= \frac{ash\ weight}{sample\ weight} x100\%$

Volatile matter

One gram sample was taken and placed on a known weighted porcelain plate. The samples were put in an oven with temperature 950 ± 20°C for 7 minutes, then were cooled in a desiccator until the condition stabilized and weighed. Volatile matter is calculated by the formula:

Volatile matter $= \frac{B-C}{W} x100\%$

Calorific value

One gram of test sample was taken and was put in a silica plate and tied with a nickel wire. The sample is then put into a tube and closed tight. The tube was oxygenated for 30 seconds. The tube was inserted in Oxygen Bomb Calorimeter. The burning starts when the water temperature is fixed with the optimum temperature measurement. The amount of calorific value according to the equation as follows:

NK $= \frac{\Delta t\ x\ W}{Mbb} - B$

Where:

NK = calorific value (cal/g)

Δt = average temperature difference (°C)

Mbb = fuel mass

B = hot iron wire correction (cal g^{-1})

Fixed carbon

The determination of fixed carbon value was carried out after the results of the volatile matter content and ash content was known and calculated by the formula:

Fixed carbon = 100 - (Water content + volatile matter + ash content)

Where:

B = sample weight after being dried from the water content test (g)

C = sample weight after oven-dry (g)

W= sample weight before water content test (g)

Data analysis

This study used a complete randomized design model (CRD) with 5 treatments and 3 replications so that the total of test samples is 5 x 3 = 15 test samples. Analysis of Variances (ANOVA) measure was used to compare significant differences and continue with Duncan's Multiple Range test (DMRT) is a post hoc test to measure specific differences between pairs of means. Statistical analysis was performed by using Microsoft Excel. The treatments are:

A = 100% ironwood sawdust *(control)*

B = 70% ironwood sawdust + 30% meranti and balsa sawdust

C = 30% ironwood sawdust + 70% meranti and balsa sawdust

D = 100% meranti and balsa sawdust.

Results and discussion

Moisture content

The highest moisture content was found in treatment D (100% of Meranti and Balsa mixed wood dust) of 6.970% and the lowest was in treatment B (70% ironwood and 30% Meranti and Balsa mixed wood dust) of 2.150% (Fig. 1). This difference in moisture content is caused by differences in physical properties of the raw materials used. This is reinforced by the opinion of Sa'adah (2014) which states that wood heated to a temperature of 110ºC - 270ºC experiencing moisture content evaporation process and some wood components begin to decompose. The high value of moisture content can decrease the calorific value of burning, slow down the combustion process, and cause air pollution because it gives a lot of smoke when it burned (Nurwigha, (2012) in Tyas, H.N (2015)). Treatment A (5.210%), B (2.150%) and C (5.730%) were in conformity with the American standard, which required a moisture content of 6%, while the D treatment (6.970%) was not, but it was in conformity with the SNI standard (<10%).

Table 1. The result of variance analysis moisture content.

Sorce of variation	df	SS	MS	F	P value	
					5%	1%
Between	3	37,741	12,580	12,94 **	4,07	7,59
Within	8	7,780	0,973			
Total	11	45,522				

** = significant; coefficients diversity = 19,66%.

Table2. Duncan test results of moisture content.

Treatment	MS	Sign.		
		D	C	A
D	6,97			
C	5,73	1,24 ns		
A	5,21	1,76 ns	0,52 ns	
B	2,15	4,82 **	3,58 *	3,06*
Duncan	5%	2,62	2,73	2,79
	1%	3,41	4,03	4,14

ns = not significant; * = significant p < 0,05; ** = significant p < 0,01.

The result of variance analysis (Table 1)showed that the composition of 70% ironwood and 30% mixed wood (Meranti and Balsa) waste had a significance effect so that Duncan posthoc test was performed. Duncan test results (Table 2)showed that the B treatment of 70% ironwood and 30% of mixed wood (Meranti and Balsa) dust was the best treatment compared to D, C and A. The high moisture content will cause calorific value to decline and the higher moisture content value in a material, the value of the produced calorific will be lower.

Table3. The result of variance analysis density.

Sorce of variation	df	SS	MS	F	P value	
					5%	1%
Between	3	0,049	0,016	4,43*	4,07	7,59
Within	8	0,029	0,004			
Total	11	0,078				

** = significant; coefficients diversity = 8,50%.

Tabel 4. LSD test result of density.

Treatment	MS	Sign.		
		B	A	C
B	0,77			
A	0,77	0,01 ns		
C	0,69	0,08 ns	0,07 ns	
D	0,62	0,16 **	0,15 *	0,08
LSD	5%	0,11		
	1%	0,17		

ns = not significant; * = significant p < 0,05; ** = significant p < 0,01.

Huthtinen (2005) in Rahmatullah, A (2014) states that the moisture content of biomass raw materials can affect the net calorific value generated during energy conversion. High moisture content causes a decrease in the resulting calorific value. This is because in the process of energy conversion, many calories are needed to remove water from the wood into steam so that the energy remaining in the fuel becomes small.

Table5. The result of variance analysis volatile matter content.

Sorce of variation	df	SS	MS	F	P value	
					5%	1%
Between	3	97,121	32,374	2,82 ns	4,07	7,59
Within	8	91,918	11,490			
Total	11	189,039				

ns = not significant; coefficients diversity = 4,64%.

Density

Density can be one indicator of biomass quality estimator. The average result of ironwood and mixed (Meranti and Balsa) sawdust biopellet was presented in Fig. 2 below.

The highest density was found in treatment B (70% Ironwood + 30% of Meranti and Balsa mixed wood dust) of 0.773 g/cm3 and the lowest was in treatment D (100% of Meranti and Balsa mixed wood dust) of 0.616 g/cm3. According to Tyas (2015) wood that has a high density tends to produce high calorific value. This is reinforced by Monteas *et.al.* (2011) suggesting that wood density has a positive correlation to the resulting calorific value. According to Winata (2013), the high and low of the density values are influenced by the specific gravity of the materials.

Table 6. The result of variance analysis ash content.

Sorce of variation	df	SS	MS	F	P value	
					5%	1%
Between	3	0,931	0,310	24,21**	4,07	7,59
Within	8	0,103	0,013			
Total	11	1,033				

** = significant; coefficients diversity =7,21%.

The specific gravity itself is influenced by the particle size of the material, where the coarser or finer the size of the biopellet particles the smaller the specific gravity thus the smaller the resulting density. Factors that affecting biopellet density are particles and size, where the size of the coarser particles has a smaller specific gravity resulting in smaller density values. All the density values meet the American standard of (>0.46 g/cm2) where treatment A (0.766 g/cm2), B (0.773 g/cm2), C (0.694 g/cm2) and D (0.616 g/cm2).

Table 7. LSD test result of ash content.

Treatment	MS	Sign.		
		A	D	C
A	1,92			
D	1,74	0,17		
C	1,41	0,50	0,33	
B	1,20	0,71**	0,54 **	0,21*
LSD	5%	0,21		
	1%	0,31		

ns = not significant; * = significant p < 0,05; ** = significant p < 0,01.

The variance analysis result (Table 3) showed that the composition of 70% Ironwood and 30% mixed wood (Meranti and Balsa) waste had a significance effect so that LSD test was done. The LSD test results(Table 4) showed that treatment D (100% of Meranti and Balsa mixed wood dust) was the best treatment compared to treatments B, A, and C. Low-density values can accelerate combustion compared to high-density materials, but may result in low calorific values. This is due to the materials with low density having an air cavity or a gap that can be passed by oxygen in the combustion process, but has a low woody substance per unit volume of wood or low lignin content as well as extractive substance (Hanun, 2014).

Table 8. The result of variance analysis colorific value.

Sorce of variation	df	SS	MS	F	P value	
					5%	1%
Between	3	1276174,379	425391,460	2,18 ns	4,07	7,59
Within	8	1561797,557	195224,695			
Total	11	2837971,936				

ns = not significant; coefficients diversity = 9,81%.

Volatile matter content

Volatile matter content is the content of substances which easily evaporates on 950^{0}C heating. The content of volatile matter such as CO, CO_2, CH_4, and H_2C (Satmoko *et al.,* 2013). The average value of the test result volatile matter content can be seen in Fig. 3.

Levels of volatile matter tested at various treatments ranged from 68.450% - 76.133%. According to Ragland and Aerts (1991) in Tyas (2015), the content of the wood biomass volatile matter ranges from 70% - 90%. The content of volatile matter is instrumental in determining the combustion properties.

The highest concentration of volatile matter was found in treatment D (100% of Meranti and Balsa mixed wood dust) which was 76.133% and the lowest was in treatment B (70% Ironwood + 30% Meranti and Balsa mixed dust) of 68.450%.

Table 9. The result of variance analysis fixed carbon content.

Sorce of variation	df	SS	MS	F	P value	
					5%	1%
Between Within	3	332,253	110,751	7,28*	4,07	7,59
	8	121,712	15,214			
Total	11	453,965				

** = significant; coefficients diversity = 20,20%.

According to Satmoko (2013) explains that the easier the raw materials burned and ignite the faster the rate of combustion. Furthermore, it is explained that the high content of volatile matter has several advantages such as easier ignition and combustion, but have a weakness that results in lower fixed carbon values. Volatile matter content of the tested woods is smaller than 85% so that the woods are considered good for use as raw materials of biomass energy (Rahmatullah, 2014). Airborne content levels in the American standards are not required.

The results of the variance analysis (Table 5) showed that the mixture treatment of Ironwood and mixed wood (Meranti and Balsa) dust did not significantly affect the content of volatile matter. Yuniarti *et.al* (2011) states that high levels of volatile matter will reduce the value of fixed carbon, thereby lowering the value of the resulting heat. High levels of volatile matter can cause emissions and air pollution at the time of combustion (Hanun F, 2014).

Ash content

As seen in Fig. 4, in treatment A (100% Ironwood dust) has the highest ash content of 3.700% and the lowest ash content was in treatment B (70% Ironwood + 30% wood dust mixed with Meranti and Balsa) of 1.457%. The high amount of ash content produced is affected by the densification process. The heat emerging during densification reduces the ash content of biopellets because the inorganic mineral content of the ash is triggered by evaporation during densification (Liliana, 2010).

Tabel 10. Duncan test result of fixed carbon content.

Treatment	MS	Sign.		
		B	C	A
B	27,94			
C	18,54	9,40 tb		
A	16,91	11,03*	1,63 tb	
D	13,84	14,10**	4,70 tb	3,07 tb
Duncan	5%	10,38	10,80	11,05
	1%	13,50	15,92	16,37

ns = not significant; * = significant p < 0,05; ** = significant p < 0,01.

According to Rajvanshi (1986) in Lubis, AS *et al.* (2016) ash content less than 5% belongs to the category of good energy materials because it does not cause the formation of mineral crust. Rahmatullah (2014) mentioned that the ash components consists of potassium, calcium, silica, and magnesium. Of all treatments only B treatment (70% Ironwood + 30 % wood dust mixed with Meranti and Balsa) that fall within the American standard, which less than 1.50% (<1.5%) of ash.

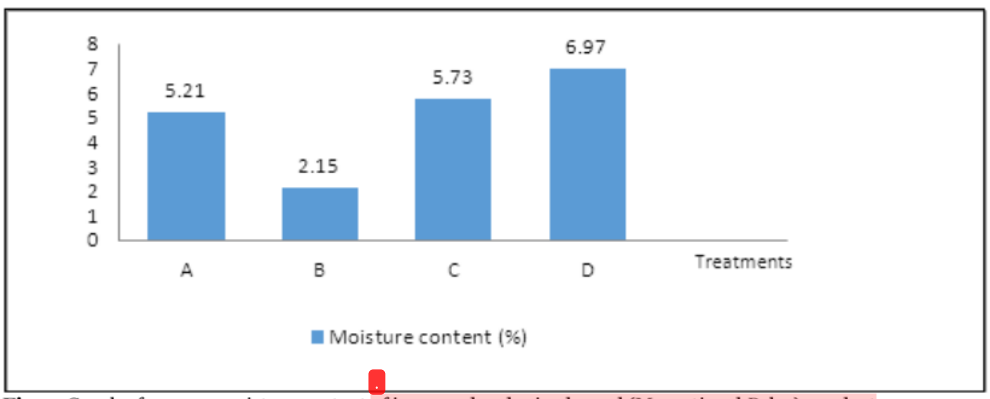

Fig. 1. Graph of average moisture content of ironwood and mixed wood (Meranti and Balsa) sawdust.

The results of the analysis of variance presented in Table 6 showed that the treatment had a very significant effect, so that the LSD follow-up test was conducted. Further BNT test results(Table 7) showed that treatment B (70% Ironwood + 30% wood dust mixed with Meranti and Balsa) was significantly different from the treatment of A, D, and C.

Wood type factor is very influential on the high level of ash. This is because the type of wood tested has different chemical composition and minerals so that the resulting ash content is different as well (Hanun, 2014). This is confirmed by Fang *et al*. (2013) which explains that high ash content affects the calorific value. High ash levels also cause the formation of deposits or crust at the time of combustion causing dirt on the furnace surface, corrosion and lowering thermal productivity that can reduce the quality of combustion (Saputro *et al*., 2012).

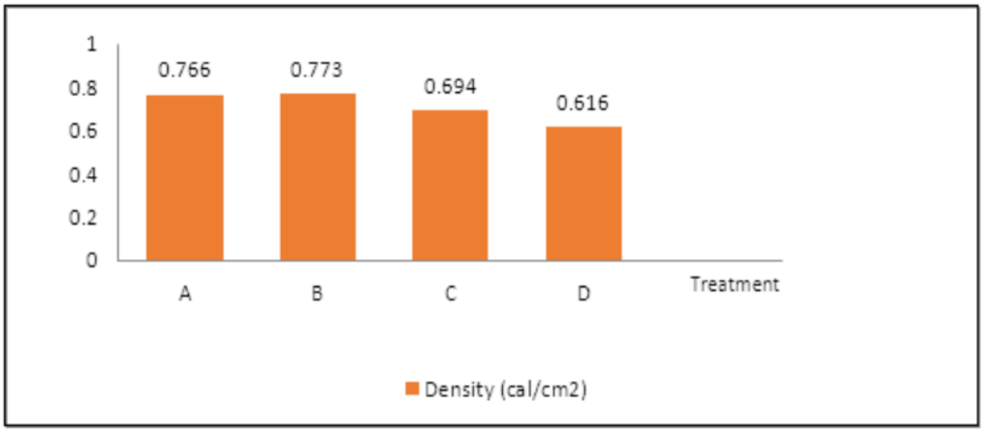

Fig. 2. Graph of average density result of ironwood and mixed (Meranti and Balsa) dust.

Calorific value

Calorific value is a key indicator in determining the quality of raw materials for energy sources that are affected by chemical composition, moisture content and ash content in wood (Silva *et al*., 2011). The average calorific value test is presented in Fig. 5 below.

The highest calorific value was in treatment B (70% Ironwood + 30% of Meranti and Balsa mixed wood dust) is 4,830.193 cal/g and the lowest was in treatment D (100% of Meranti and Balsa mixed wood dust) which amounted to 3,974.440 cal/g.

The results showed that mixed materials of 70% Ironwood and 30% Meranti and Balsa wood waste mixture had the highest calorific value. Figure 5 shows that the more mixture of Ironwood dust waste, the higher the calorific value produced.

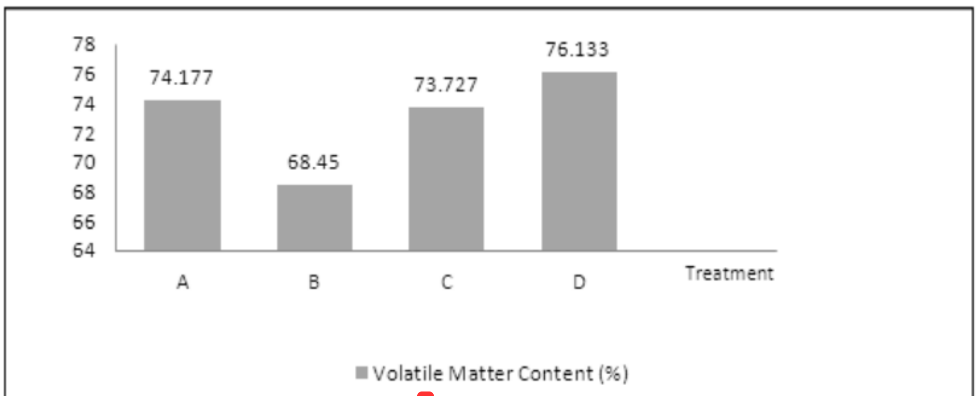

Fig. 3. Graph of average volatile matter content of Ironwood and mixed wood (Meranti and Balsa) dust.

Calorific value is the result of the interaction of various chemical components of the wood compiler. According to Basu (2010), the factors that affect the calorific value are moisture content, ash content, volatile matter content and fixed carbon content. The high calorific value will result in efficient combustion and save the raw materials of biomass energy (Jamilatun, 2011). This is due to slower burn rate with the increasing of calorific value (Tiruno and Sabit, 2011).

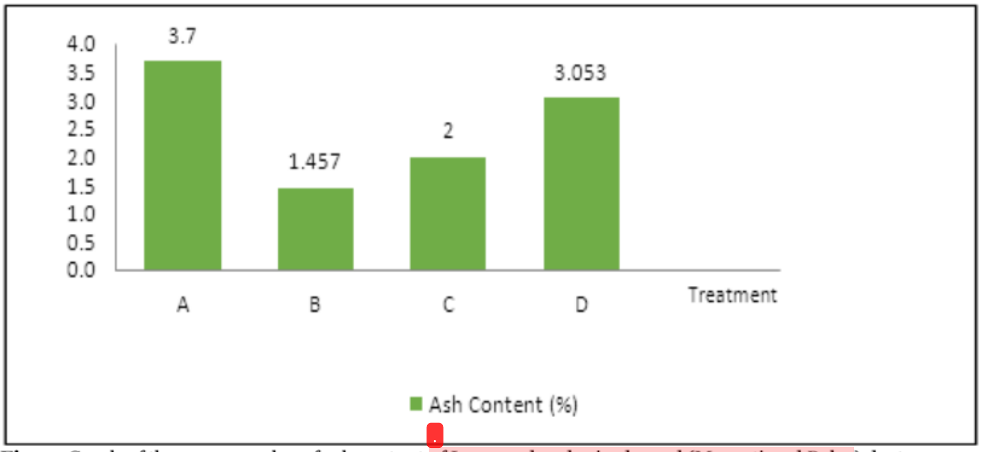

Fig. 4. Graph of the average value of ash content of Ironwood and mixed wood (Meranti and Balsa) dust.

The calorific value of biopellet is directly proportional to the fixed carbon content, the higher the fixed carbon content, the higher the calorific value.

The fixed carbon is influenced by a number of non-carbon compounds that have evaporated in the densification process (Hendra, 2012). Calorific value is inversely proportional to moisture content, the higher the moisture content the lower the calorific value (Onu *et al*, 2010). In addition, Yanti (2013) states that caloric value is closely related to the moisture content and the density of biopellet produced, the lower the moisture content, the density of biopellet will increase, and the more dense biopellet produced, the calorific value will increase.

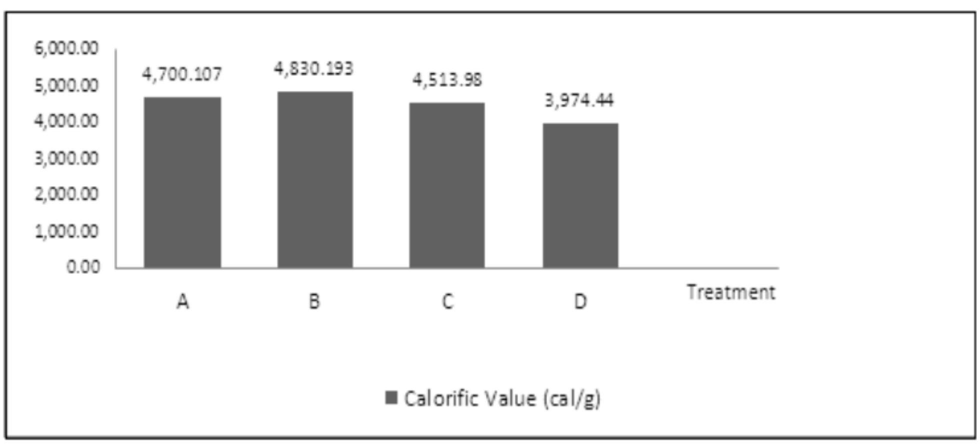

Fig. 5. Graph of average heating value of Ironwood and mixed (Meranti and Balsa) dust.

The higher the calorific value indicates better fuel quality (Rahman, 2011). The results of the tests that conform to the American standard (>4579.2 cal/g) were found in treatment B (70% Ironwood + 30% mixed wood Meranti and Balsa dust) of 4,830.193 cal/g and treatment A (100% Ironwood) of 4700.107 cal/g. The diversity analysis results (Table 8) showed that the mixture treatment of Ironwood and of Meranti and Balsa mixed wood dust had no significant effect on the calorific value.

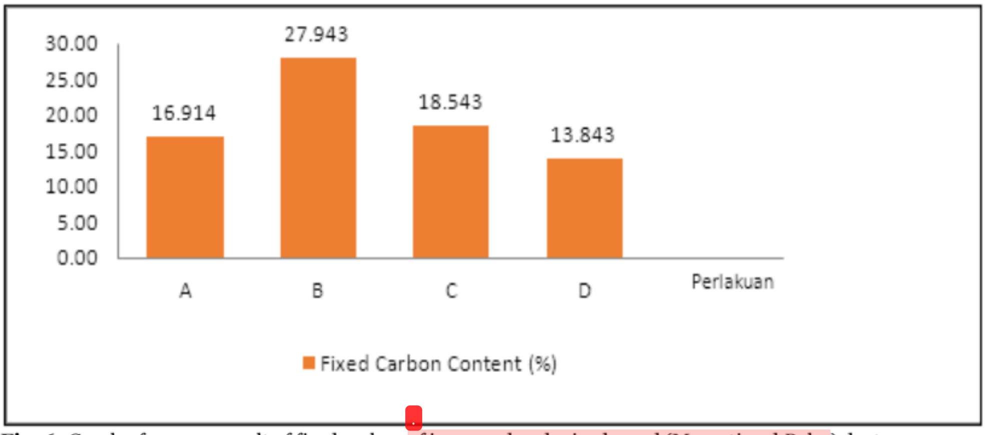

Fig. 6. Graph of average result of fixed carbon of ironwood and mixed wood (Meranti and Balsa) dust.

Fixed carbon

Fixed carbon has an important role in determining the quality of biopellet because it will affect the calorific value of biopellet. The fixed carbon value is obtained by calculating the 100% weight of the sample minus the amount of moisture content minus the ash content and minus the volatile matter content. The fixed carbon is a solid fuel left inside the furnace after the volatile material was distilled. The average result of fixed carbon testing can be seen in figure 6.

Fig. 6 shows that the fixed carbon value is inversely proportional to the value of the volatile matter content but is proportional to the ash content. The highest fixed carbon values were in treatment B (70% Ironwood + 30% wood mixture of Meranti and Balsa dust) which is 27.943% and the lowest is in treatment D (100% of Meranti and Balsa mixed wood dust waste) which is 13.843%. The addition of 70% of Ironwood and 30% Meranti and Balsa mixed wood dust resulted in the highest value of fixed carbon. Hasanuddin, *et al* (2012) suggests that the fixed carbon content is affecting the calorific value, the higher the fixed carbon, the higher the calorific value because each oxidation reaction produces a calorific value. The American standard does not require fixed carbon valuation.

The results of the variance analysis (Table 9) showed that the mixture of Ironwood and mixed wood of Meranti and Balsa dust had a significance effect so that Duncan posthoc test was performed. Duncan test results (Table 10)showed that B treatment (70% Ironwood + 30% mixed wood Meranti and Balsa dust) is the best treatment compared with the treatment of C, A and D.

Conclusion

The best biopellet characteristic was found in treatment B (70% of ironwood + 30% waste of Meranti and Balsa mixed wood dust) with 2.150% moisture content, 0.773 g/cm3 density, 68.450% volatile matter content, 1.204% ash content, 4,830.930 cal/g calorific value and 27.943% fixed carbon value. The influencing factors are the raw materials and the biopellet processing. The quality of biopellet affecting the American standard for moisture content (<6%) was found in treatment A (100% of Ironwood dust) of 5.210%, B (70% of Ironwood + 30% of Meranti and Balsa mixed wood dust) of 2.150% and C (30% of Ironwood + 70% of Meranti and Balsa wood dust) amounted to 5.730%. Density with (>0.64 g/cm3) was found in the treatment A of 0.766 g/cm3, B (0.773 g/cm2), C (0.694 g/cm2) and D (0.616 gr/cm2). Ash content for standard quality biopellet (<3%) only found in treatment B that is 1.457%. The calorific value (>4,579.2 cal/g) was found in treatment A that is 4,700.107 cal/g and treatment B is 4,830.193 cal/g. The value volatile matter and the fixed carbon are not required.

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