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THE QUALITY OF BIOPELLET FROM COMBINATION OF PALM SHELL CHARCOAL AND PALM FIBER

MUTU BIOPELET DARI CAMPURAN ARANG DAN SABUT CANGKANG SAWIT

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ABSTRAK

Biomassa pelet (biopelet) adalah bahan bakar padat berbentuk silinder yang dapat menjadi alternatif energi untuk masyarakat pedesaan. Cangkang dan serabut sawit adalah biomassa potensial yang dapat dikonversi menjadi biopelet. Peletisasi dapat meningkatkan kualitas dan karakteristik pembakaran biomassa. Tujuan dari penelitian ini adalah untuk mempelajari pemanfaatan cangkang sawit dan serabut sawit melalui pembuatan biopelet dan untuk mengetahui pengaruh penambahan cangkang sawit dan serabut sawit. Konsentrasi arang cangkang sawit dan serabut sawit yang digunakan adalah 0%, 10%, and 20%. Proses karbonisasi dilakukan menggunakan kiln drum selama ± 4,5 jam pada temperatur 450°C. Proses densifikasi dilakukan menggunakan alat pellet mill dengan kapasitas 10 kg/jam dimana diameter dies adalah 15 mm pada temperatur 250°C selama 2 menit waktu pengepresan. Penelitian dimulai dengan menganalisis sifat fisiko kimia bahan. Kemudian hasil analisa dilanjutkan dengan analisa karakterisasi pembakaran. Berdasarkan sifat fisiko kimia dan karakterisasi pembakaran; biopelet cangkang sawit yang terdiri dari 80% cangkang sawit dan 20% arang cangkang sawit merupakan biopelet dengan kualitas terbaik. Biopelet tersebut memiliki kadar air 0,47%; kadar abu 9,83%; kadar zat terbang 55,34%; kadar karbon terikat 34,84%; nilai kalor 5.265,92 kkal/kg; densitas kamba 1.260,30 kg/m^3; dan keteguhan tekan 82,09 kg/cm^2. Rata-rata laju konsumsi biopelet cangkang sawit adalah 1,39 kg/jam dan nilai efisiensi pembakaran adalah 11,59%. Produksi biopelet cangkang sawit pada skala laboratorium menghasilkan rendemen sebesar 11,54%. Biopelet dapat meningkatkan nilai kalor bahan baku cangkang sawit sebesar 15,55%.

Kata kunci: *biopelet, cangkang sawit, serabut sawit, arang, karbonisasi*

ABSTRACT

Biomass pellet (biopellet) is a biomass-based solid fuel with tubular solid form which is one of alternative energy for rural community. The abundance of palm shell and palm fiber is a potential source of biomass that can be converted into biopellet. Pelletization can improve the quality and burning characteristics of biomass. The purposes of this research were to study the utilization of palm shell and fiber into biopellet production and to assess the addition affectation of palm shell charcoal and palm fiber. The percentages of palm shell charcoal and palm fiber were 0%, 10%, and 20%. Carbonization process was done by using kiln for ±4.5 hours at 450°C. Densification process was done by using pellet mill whose the capacity was 10 kg/hour with a dies diameter of 15 mm and at temperature of 250°C for 2 minutes of pressure time. The research was started with an analysis of physico-chemical properties of the raw material and then followed by analysis of combustion characteristics. Based on the physic-chemical properties and the combustion characteristics; biopellet of palm shell that contained 80% of palm shell and 20% of palm shell charcoal has the best quality. It has 0.47% of moisture content; 9.83% of ash content; 55.34% of volatile substances; 34.84% of fixed carbon; 5,265.92 kcal/kg of heating value; 1,260.30 kg/m^3 of bulk density; and 82.09 kg/cm^2 of strength pressure. The consumption rate was 1.39 kg/hour and the combustion efficiency was 11.59%. The production of palm shell biopellet on a laboratory scale produced yield of 11.54%. Biopellet increased heating value of palm shell for 15.55%.

Keywords: biopellet, palm shell, palm fiber, charcoal, carbonization

INTRODUCTION

The world has been facing many environmental problems due to uncontrolled resource exploitation and waste generation. Immediate effects of these human activities to environment are resource depletion and environmental pollution. The main causes of current problems are the growing use of fossil fuel and high waste production, both bearing directly upon climate change. To deal with this situation, many scholars have been paying serious attention to utilization of biomass energy generating from agriculture, industrial and domestic wastes (Bergman and Zerbe, 2004; Birol, 2007; Dinica, 2009; Mamun *et al.*, 2009; Periyasamy, 2011; Rofiqul *et al*., 2009).

Biomass is a potential, clean and renewable source of energy that is produced by photosynthesis

**Penulis untuk korespondensi*

(García-Maraver *et al.,* 2010). Overall, the global potentials range from 30% to over than 200% of current total energy consumption. In the case of Indonesia, Prihandana and Hendroko (2007) calculated that the biomass energy potential of 50,000 MW comes from agricultural wastes, such as by-products of palm oil mills, rice mills, cane sugar mills, and others. In addition to these sources of biomass include animal wastes, organic wastes such as municipal solid wastes, bio-energy from natural growth forests, and water-based biomass such as micro-algae. However, this considerable potential does provide some indication as to the vast scale of land resources and the low levels of current utilization (Johnson and Matsika, 2006). Comprehensive approach and systematic development of alternative energy for rural communities through massive utilization of biomass will improve world people capacity to access modern energy supply (IEA ,2010).

The components of biomass are cellulose, hemicelluloses, lignin, lipid, protein, starch, simple sugar, water, ash, and other compounds (Jenkins *et al*., 1998), whereas the main components are carbon (C), oxygen (O), and hydrogen (H) (McKendry, 2001). Utilization of biomass as energy has several advantages (Maraver *et al*., 2010), namely provides socio-economic and environmental benefits, reduce carbon emissions, and play an important role in the national economy by reducing, limiting or avoiding the import of fossil fuels. According to El Bassam and Maegard (2004), biomass was used as a fuel generally has low economic value or the result of extraction of primary products.

Among biomass energy sources that potential for bio-fuel are palm shell and palm fiber that are generated in the production of Crude Palm Oil (CPO) (Sulaiman *et al.,* 2010). These wastes are not utilized optimally yet create a serious problem for the Palm Oil Mill and the surrounding communities. According to the Directorate General of Plantations (2010), Indonesia oil palm plantation area in 2010 was 7.82 million hectares and the average production of fresh fruit bunches (FFB) is 16 tons per hectare. In general, palm shell and palm fiber generation at 6.5% and 13% of the total FFB processed (DG PPHP 2006). Thus, every year there are about 8.13 million tons of palm shell and 16.26 million tons of palm fiber. Utilization of these wastes will provide a good energy resource and has implication to sustainable development (Md Nor and Rostam, 2011).

The technology of biomass utilization for modern energy purposes has been developed for generating electricity and steam that emphasizes the medium and large scale of industries needs. Although biomass is a clean fuel source and renewable energy, it has poor physical properties when it's burned directly due to its low energy density and its handling, storage, and transportation (Saptoadi, 2006). Direct uses without pre-treatments may cause respiratory problems that associate with carbon monoxide (CO), sulfur dioxide (SO_2), particulate matter and other sediments (Yamada *et al*., 2005). The quality of biomass as fuel can be increased by converting them into better and more uniform shape, so easy to handle, transport, and storage, improving combustion, increasing fuel efficiency, so have higher energy density. Biomass pellet is a technology to increase the burning quality of biomass fuel (Bergman and Zerbe, 2004).

Biomass pellet was known as biopellet is a solid biomass-based fuel with tubular solid form. Biopellet's density and size uniformity are better than briquettes. The main process used is compression with high temperature and pressure, thus forming a uniform product. Pellets can be produced easily from wood wastes and other biomass materials (Yang *et al*., 2005). In some countries such as Germany and Austria, biopellet has been developed as an alternative fuel that derived from wood pieces and produced by crushing wood using a hammer mill, resulting in a uniform mass of wood particles. The mass of wood particles is fed into the press machine (Mani *et al*., 2006). The advantages of biopellet are higher caloric value and easier process of moving (transportation) from one place to another due to its uniformity of size (Battacharya, 1998). Pellet is the result of biomass compression with higher pressure than briquettes, which are 650 kg/m^3 versus 60 kg/m^3.

The combustion heat or calorific value that resulted in the combustion process is one of the parameters to determine the quality of biomass fuel. The enhancement of calorific value of biomass fuel can be done by adding some of other materials with better calorific value. In general, the carbonized biomass waste has higher calorific value. The aim of this study was to improve the quality of pellets from palm shell charcoal and palm fiber. The biopellet was made using primary raw material of palm shell and additives materials of palm shell charcoal and palm fiber. At the end of this study, the best biopellet formulation was selected based on its high calorific value and quality parameters for further analysis i.e. combustion analysis, mass balance, cost production and comparison with other fuels for application purpose.

MATERIAL AND METHOD

This study initiated with preparation of raw materials, size reduction, and proximate analysis of materials, production of biopellet, proximate analysis of biopellet, analysis of the best quality of biopellet, analysis of mass balance, analysis of cost, and comparison analysis to other fuels. The flow chart method is presented in Figure 1. This study was done in Biodiesel Laboratory, Chemistry and Energy Laboratory, and Integrated Laboratory of

Forest Product Research and Development Institute, Gunung Batu, Bogor. The materials were palm shell and palm fibers that were taken from Palm Oil Mill of Nusantara Plantation VIII of Kertajaya, Malimping, Banten, Indonesia.

Screening

The purpose of screening was to separate raw material particle that produced from size reduction process. The screen should have a size of 1 mm. The biopellet size should be less than 1 mm in order to prevent the cracked biopellet.

Carbonization

Carbonization was done using carbonizer with kiln drum type, the tube high is 30 cm and the diameter is 19 cm. The palm shell was moved to the pyrolisys tube and heated for ± 4.5 hours, started from room temperature to 450°C. After heating process, the equipment was switched off for 24 hours and then the palm shell charcoal could be removed from the pyrolysis. The purposes of this process were to reduce the volatile substances and to increase the fixed carbon of the material.

Analysis of Raw Materials Properties

Proximate analysis of palm shell, palm fiber, and palm shell charcoal consist of moisture content (SNI 06-4369-1996), ash content (SNI 06-4369-1996), volatile substance content (SNI 06-4369-1996), fixed carbon content (SNI 06-4369-1996), bulk density, pressure strength, and calorific value (SNI 06-4369-1996) (SNI denotes National Standards of Indonesia Procedure). The purpose of this analysis was to know the material characteristics before used to produce biopellet.

Pelletization

Before producing biopellet, raw materials were mixed together in order to homogeneous materials. There are nine treatments: mixture of palm shell and palm fiber (0%, 10%, and 20%) and palm shell charcoal (0%, 10%, and 20%). Biopellet Production was done using pellet mill with 100 kg/cm^2 or equivalent to10^6 kg/m^2) of pressure, 10 kg/hour of the capacity, and using semi-automatic system. The process temperature was 250°C for ± 2 minutes of pressure time, 15 mm of dies diameter, and ± 10 mm of length. Biopellet was formed due to high pressure to material. Thus, biopellet which was produced in this study has diameter of 15 mm and the average length of 10 mm (refer to the French and ITEBE standards).

Drying of the Biopellet

Biopellet was dried by storing at room temperature for ± 2 hours. The purpose of this process was to dehumidify biopellet, to avoid moisture content increasing after pelletizing process.

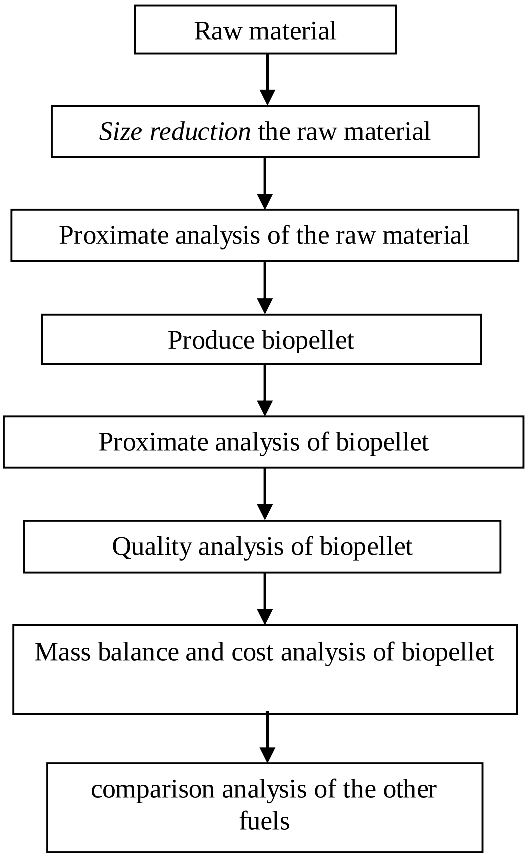

Figure 1. The flow chart of the study

Proximate Analysis of Biopellet

The proximate analysis on biopellet consist of moisture content (SNI 06-4369-1996), ash content (SNI 06-4369-1996), volatile matters (SNI 06-4369-1996), fixed carbon (SNI 06-4369-1996), calorific value (SNI 06-4369-1996), bulk density, and strength pressure. The purpose of this analysis was to know the characteristic of biopellet which is use to select the best formulation. Final analysis of the best formula was heating quality of biopellet.

Data of biopellet properties were analyzed using Completely Randomized Design (CRD) with two factorials. For the treatment which significantly influenced the observed parameters, the analysis was continued with Duncan test. The best quality of biopellet formulation was tested for heating quality and mass balance analysis.

Analysis on Heating Quality of Biopellet

Heating quality analysis was done by using biomass stove UB – 03 series. The fuel was inserted into the fuel hole in the stove. The method in this analysis was Water Boiling Test (WBT) by boiling one liter of water. WBT is a simulating method of fuel combustion process to examine how effective the thermal energy can be transferred to the stove for heating purpose (Bailis *et al.*, 2007).

Mass Balance Analysis

Mass balance analysis of biopellet was done for the best quality of biopellet to know the final yield of the biopellet process. This process was done by using input-output method that is analysis of the mass flow in and out of each stage of processes.

RESULTS AND DISCUSSION

Raw Material Characteristics

For properties analysis purpose, the materials were dried in the sun to reduce their moisture content to less than 12% (w/w). Then, they were reduced in size to a uniform particle of 1 mm diameter. The proximate analysis parameters were moisture content, ash content, volatile matters, fixed carbon, calorific value, and bulk density. The result of this analysis is presented in Table 1.

Table 1. The proximate analysis of raw materials powder

Properties	Unit	Value: Palm Shell	Value: Palm Fiber
Moisture	%ww	8.91	11.52
Ash	%ww	13.35	18.94
Volatile matter	%ww	78.64	77.03
Fixed carbon	%ww	8.01	4.03
Caloric value	kcal/kg	4,557.08	4,048.08
Bulk density	kg/m^3	713.97	104.10

The moisture contents of palm shell and palm fiber (8-12%) meet the requirement as described by many biopellet researchers (Tabil, 2011). This indicated that biopellet would have high density, durability, and calorific value. The main parameter to determine heating quality of biopellet is calorific value of material. The calorific value of these materials were higher than the one of rice husk (3,450 kcal/kg), sawdust (3,580.36 kcal/kg), and jatropha cake (4,414.33 kcal/kg) (Chin and Siddiqui, 2000; Liliana, 2010; Rahman, 2011). In addition to calorific value, they contain high volatile substances and ash (Dagwa *et al.*, 2012; Yunos *et al.*, 2012). Thus, converting them into a biopellet could reduce both volatile substances and ash together with increasing fixed carbon content.

Carbonization is biomass combustion with limited oxygen to increase its calorific value and fixed carbon content. Lack of oxygen will push out volatile substances, while carbon components will stay in the material. Carbonization of palm shell at temperature of 450°C for 4 hours and 30 minutes yielding 46% (w/w) of its original weight. The results of proximate analysis of palm shell charcoal are presented in Table 3. In addition to energy purposes, carbon which was made from oil palm shell has wide uses and applications (Khalil *et al.*, 2011; Hossain *et al.*, 2012; Ngarmkam *et al.*, 2011; Wong and Ani, 2007).

Table 2. The proximate analysis of palm shell charcoal

Properties	Unit	Palm Shell	Palm Shell Charcoal
Moisture	%ww	10.00	2.70
Ash	%ww	6.59	11.40
Volatile matter	%ww	78.29	26.53
Fixed carbon	%ww	11.71	70.77
Caloric value	kcal/kg	4,557.08	5,921.68
Bulk density	kg/m^3	713.97	426.63

The moisture content and volatile substances were reduced during carbonization process; whereas fixed carbon content and the calorific value were increased. The moisture content was evaporated at high temperature, then continued during storage that caused by environmental conditions that relate to its hygroscopic characteristic. The charcoal surface has empty pores, thus its particles easily release and absorb water depending on environmental conditions (Bhattacharya, 1998; García-Maraver, 2010; Jenkins *et al.*, 1998).

Biopellet of Palm Shell

Pellet has 1% of ash content and less than 10% of moisture content (El Bassam and Maegaard 2004). For that purposes, biopellet was made from palm shell with the addition of palm shell charcoal and palm fiber to improve calorific value and fixed carbon content. It is based on the influence of charcoal amount on reduction of bulk density of biopellet. Addition of palm fiber was to increase the adhesive power of biopellet which is based on the lignin content of palm fibers (27.86% w/w) and cellulose content (28.28%) (Pari *et al*., 2001). The high lignin content of palm fibers would melt during densification process at high temperature and pressure, react with the material and provide better biopellet. Figure 2 shows the biopellets of palm shell in this study.

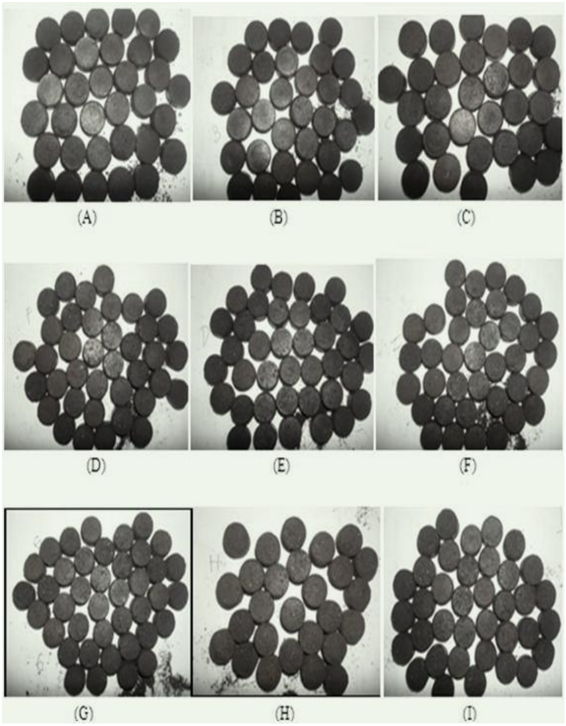

Figure 2. Biopelet of palm shell with the formulation palm shell: palm shell charcoal: palm fiber (A) 100:0:0 (B) 90:0:10; (C) 80:0:20; (D) 90:10:0; (E) 80:10:10 (F) 70:10:20; (G) 80:20:0; (H) 70:20:10; (I) 60:20:20

Moisture content

The moisture content has influence on net calorific value, combustion efficiency, combustion temperature and moisture content equilibrium with the ambient moisture content that affecting storage conditions (Lehtikangas, 2001). It is influenced by treatment, material composition, weight of the material and drying process. The results of moisture content analysis are presented in Figure 3.

The moisture content of biopellet in this study range from 0.47 to 1.12%. The highest moisture content was in composition of 80% of palm shell and 20% of palm fiber and the lowest was 80% of palm shell and 20% of palm shell charcoal. There is no interaction of adding palm shell charcoal and palm fiber. However, the effect of their percentages was significantly different ($\alpha = 0.05$) to the moisture content of the biopellet. The charcoal was known to have significant influence to quality properties of biopellet.

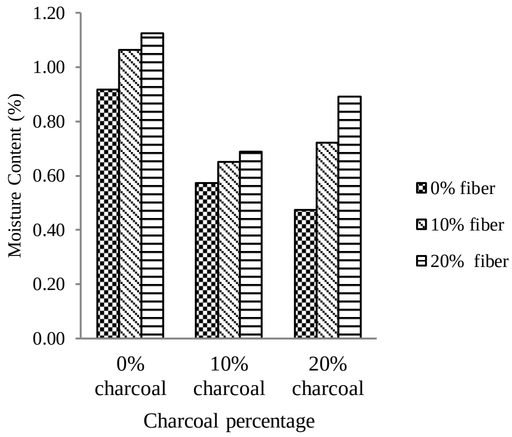

Figure 3. The effect of the percentage of palm shell, palm shell charcoal, and palm fibers to the moisture content of biopellet

Palm fiber has the higher moisture content and the cork cells make easier to absorb water so its addition increased the moisture content of biopellet. In contrast, palm shell charcoal reduced the moisture content of biopellet due to its lower moisture content. The moisture content of biopellet in this study attained the standards of pellet for some countries (Table 3).

Table 3. The comparison of moisture content of palm shell biopellet with biopellet from some countries

Sources	Moisture content (%)
Austria (ONORM M 7135)	<10
Germany (DIN 51371)	<12
Sweden (SS 18 71 70)	≤10
Italy (CTI – R 04/5)	≤10
France	≤15
Result of the study	0.47 – 1.12

Ash content

Ash is produced during the combustion process of fuel and consists of minerals which left after incineration process. It may affect the combustion efficiency by producing slag or scale on the walls of the stove that is very hard to be removed, so the furnace efficiency will decline (Ohman *et al.*, 2009). The ash content of palm shell biopellet is presented in Figure 4. In order to maintain a high operating that comfort for end users in the residential heating sector, high ash content must be avoided (Obernberger and Thek, 2004).

The ash content of biopellet in this study range from 9.83% to 14.94% (w/w). The highest ash content of biopellet was in composition of 80% of palm shell and 20% of palm fiber and the lowest was 80% of palm shell and 20% palm shell charcoal. There are no interaction of adding palm shell charcoal and palm fiber. However, the effect of their percentages was significance ($\alpha = 0.05$). At no palm shell charcoal addition has similar influence of those no addition of palm fiber that were significantly different (α=0.05) to the ash content of the biopellet. The carbonization process with limited oxygen decreased the ash content of biopellet.

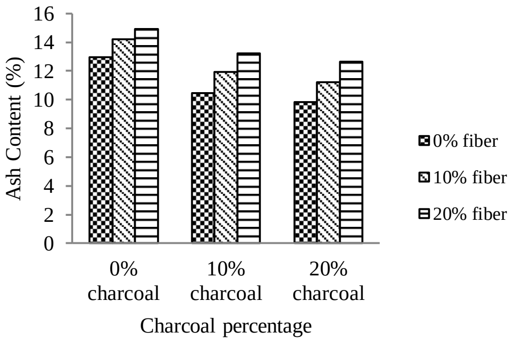

Figure 4. The effect of the percentage of palm shell, palm shell charcoal, and palm fibers to the ash content of biopellet

The ash content of palm shell biopellet did not meet the standards of Austria, Germany, America, and France. This content was higher than jatropha cake biopellet (4-6%) (Liliana, 2010) and met the standard of France (ITEBE), but lower than rice husk biopellet which range from 15.24-20.00% (Rahman, 2011). The comparison of ash content of biopellet obtained in this study and the standards of some countries is presented in Table 4.

Table 4. The comparison of ash content of palm shell biopellet with biopellet from some countries

Sources	Ash content (%)
Austria (ONORM M 7135)	<0.50
Germany (DIN 51371)	<1.50
America	<2.00
France	<6.00
Result of the study	9.83 - 14.94

Volatile Matters

The volatile matters are evaporated as decomposition product of the compounds that contained in the charcoal except water (Hendra *et al.*, 2000). These determine the combustion rate, burning time, and smoke content which were generated during the combustion (Hansen, 2009). The higher volatile content of the fuel, the lower the combustion efficiency with more generated smoke. The volatile matters content of palm shell biopellet range from 55.34%-72.38% (Figure 5).

The addition of palm shell charcoal and the interaction of the addition of palm shell charcoal and palm fiber were significantly different (α= 0.05) on the result of volatile matters of biopellet. In contrast, the addition of palm fiber was not significantly different. At no addition of palm fiber, all percentages (0%, 10%, and 20%) of palm shell charcoal showed same interaction (α=0.05). At the addition of 10% and 20% of palm shell charcoal and 20% of palm fiber have similar influence to the volatile substance of biopellet.

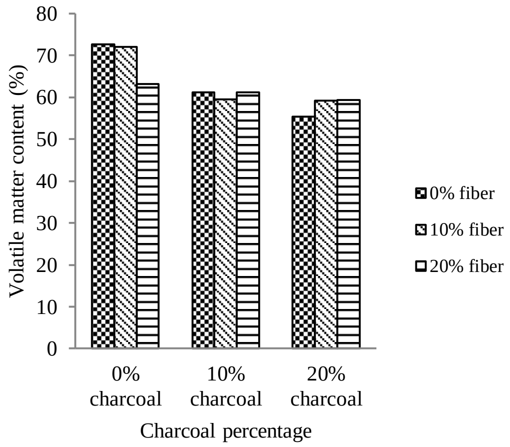

Figure 5. The effect of the percentage of palm shell, palm shell charcoal, and palm fibers tto the volatile matter of biopellet

Overall, the addition of palm shell charcoal reduced the volatile matters of biopellet. This condition was caused by the carbonization process that reduced the volatile matters and increased the carbon component. The volatile matters of palm shell biopellet (55.34-72.38%) was lower than the one of rice husk (68.14-79.94%) (Rahman, 2011).

Fixed Carbon

The fixed carbon is the carbon (C) fraction that is bonded in the material besides water, volatile matters, and ash. It consists of carbon compound and several hydrogen, oxygen, sulfur, and nitrogen. Therefore, it can be confirmed that the presence of fixed carbon in the fuel is influenced by ash and volatile matter contents (Nugrahaeni, 2008; Vitidsant *et al.*, 1999). It is also a quality parameter of its combustion. The higher of fixed carbon content, the better of combustion of biopellet. The levels of fixed carbon of palm shell biopellet range from 13.8-34.84% (Figure 6).

The addition of palm shell charcoal and the interaction of addition the palm shell charcoal and palm fiber were significantly different (α = 0.05) for the fixed carbon content of biopellet. However, the addition of palm fiber did not influence the fixed carbon of biopellet. The highest carbon content was in the formulation of 80% of palm shell and 20% of palm shell charcoal and the lowest was 90% of palm shell and 10% of palm fiber. Without addition of palm fiber, all of the percentages of palm shell charcoal significantly (α=0,05) influenced the fixed carbon content of the biopellet. At addition levels of

10% and 20% of palm shell charcoal and palm fiber had same influence with all addition levels of palm fiber to fixed carbon content of the biopellet.

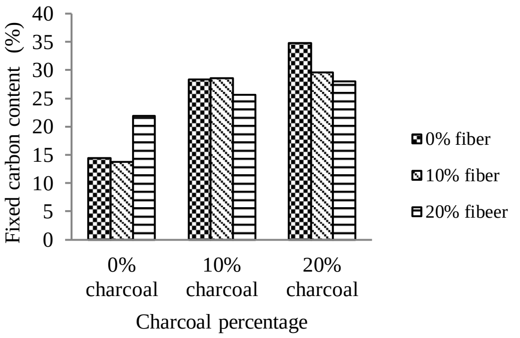

Figure 6. The effect of the percentage of palm shell, palm shell charcoal, and palm fibers to the fixed carbon of biopellet

The charcoal addition in the formulation increased the fixed carbon content of biopellet. It is caused by the carbonization process of palm shell could eliminate the volatile matters and increased the carbon compound in the carbonized material, so that the biopellet have more fixed carbon content.

Calorific Value

The gross calorific value is an important parameter to determine the fuel quality. It is affected by moisture content, ash content, and closely related to the level of fixed carbon (Celma *et al*., 2007). Low moisture and ash contents can improve the calorific value of the fuel (Lehtikanges, 2001). Therefore, materials that containing more fixed carbon have better calorific value (Bureau of Energy Efficiency ,2005). The calorific value of biopellet in this study is presented in Figure 7.

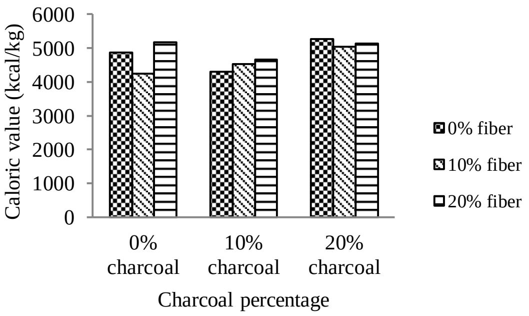

Figure 7. The effect of the percentage of palm shell, palm shell charcoal, and palm fibers to the caloric value of biopellet

The calorific value of oil palm shell biopellet was in the range of 4,242.90 kcal/kg to 5,265.92 kcal/kg. These values met the standards of some countries (Table 5). Addition and interaction of palm shell charcoal and palm fiber were significantly (α = 0.05) different on the caloric value of biopellet. The addition of palm shell charcoal improved the calorific value of biopellet. This relays to the carbon content and volatile matters of charcoal. This calorific value was higher than the ones of rice husk (4,450.36 kcal/kg) (Rahman, 2011) and jatropha cake (5,009.33 kcal/kg) (Liliana, 2010).

Table 5. The comparison of the caloric value of palm shell biopellet with biopellet from some countries

Sources	Caloric Value (kcal/kg)
Standard Austria (ONORM M 7135)	≥4,299.3
Standard Sweden (SS 18 71 70)	≥4,036.6
Standard Germany (DIN 51371)	4,179.9 – 4,657.6
Standard Italy(CTI – R 04/5)	≥4,036.6
Result of the study	4,242.90 – 5,265.92

Bulk Density

Bulk density of biopellet associates with its handling, storage, and transportation, because the storage and transport capacity decreases with an increasing bulk density (Kaliyan and Vance 2009). It may be manipulated by difference levels of pressure in densification process. The bulk density value of pellet fuel is 650 kg/m^3 (Obernberger and Thek, 2004). Figure 8 shows bulk density of biopellet in this study that range from 1,228.75 kg/m^3 to 1,429.58 kg/m^3. The highest bulk density was found in the formulation of 80% of palm shell and 20% of palm fiber and the lowest was 70% of palm shell and 20% of palm shell charcoal, and 10% of palm fiber. The addition of palm shell charcoal was inversely proportional to the value of bulk density. This condition is mainly caused by the hygroscopic properties of charcoal that have blank space or pores which reduces the bulk density.

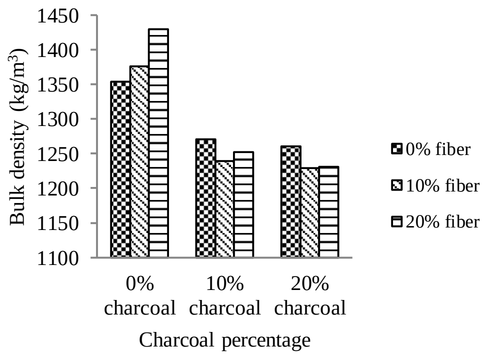

Figure 8. The effect of the percentage of palm shell, palm shell charcoal, and palm fibers to the bulk density of biopellet

The addition of palm fiber and its interaction with palm shell were not significantly different (α =0.05) on the bulk density of biopellet. However, addition of palm shell charcoal has significantly (α=0.05) different. At no addition of palm fiber, the difference was significance (α=0.05) at addition of 10% and 20% of palm shell charcoal. The bulk density of palm shell biopellet met the quality standard of several countries (Table 6).

Table 6. The comparison of bulk density of palm shell biopellet with biopellet from some countries

Sources	Bulk density (kg/m^3)
Standard Austria (ONORM M 7135)	> 1,120
Sweden (SS 18 71 20)	>600
Standard America (PFI)	> 640
Standard Germany (DIN 51371)	1,000-1,400
Standard France (ITEBE)	> 1,150
Result of the study	1,228.75 – 1,429.58

Strength Pressure

The strength pressure shows the resistance or compactness of material to external pressure that cause damage to the biopellet. The purpose of this analysis was to determine the endurance of biopellet during handling and transportation. The higher of the strength pressure of biopellet, the better endurance which may relay to handling and transportation cost. The strength pressure of palm shell biopellet range from 82,090 kg/m^2 to 354,420 kg/m^2. The highest value was found in the formulation of 80% of palm shell and 20% of palm fibers while the lowest was in the formulation of 80% of palm shell and 20% of palm shell charcoal (Figure 9).

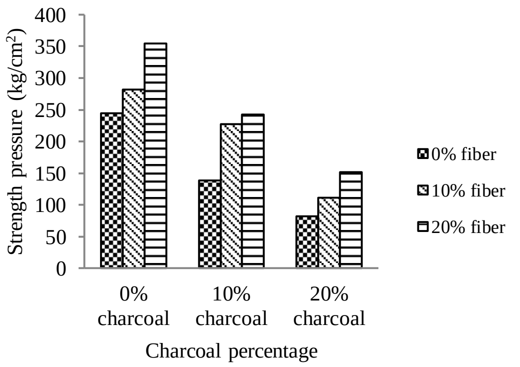

Figure 9. The effect of the percentage of palm shell, palm shell charcoal, and palm fibers to the strength pressure of biopellet

The addition of palm fiber was not significantly different (α = 0.05) on the result of the strength pressure of biopellet. In contrast, the addition of palm shell charcoal and its interaction with palm fiber were significantly different (α = 0.05). At no addition of palm fiber, palm shell charcoal have significant different (α=0.05). At 10% and 20% of palm shell charcoal, all level addition of palm fiber has same interaction to strength pressure of the biopellet.

The strength pressure of palm shell biopellet (82.09kg/cm^2- 354.42 kg/cm^2) was higher than the one rice husk (7.59 kg/cm^2-8.99 kg/cm^2) (Rahman 2011). It is influenced by particle size of the material. The smaller of the particle size of the material, so the higher the strength pressure of biopellet.

Best Formulation

According to proximate and statistical analysis, the best palm shell biopellet formulation was 80% of palm shell and 20% of palm shell charcoal. This formulation has calorific value of 5,265.92 kkal/kg, moisture content of 0.47%, ash content of 9.83%, volatile matter content of 55.34%, bulk density of 1,260.30 kg/m^3, and strength pressure of 82,090 kg/m^2. This formulation was then further analyzed for combustion, mass balance, comparison to other fuels, and production cost.

Combustion Analysis

The purpose of this analysis was to know the quality of the best formulation of palm shell biopellet when it is applied to the stove. This analysis was done by using *Water Boiling Test* (WBO) method. The parameters were the consumption rate and the combustion efficiency of palm shell biopellet.

Consumption Rate: It is the amount of biopellet mass that is progressively burned in a unit of time. The higher bulk density of the material, the slower rate of combustion. The consumption rate of palm shell biopellet was measured for three replications, so that the results were in an average consumption rate of the best formulation of palm shell biopellet (Table 7).

The average boiling time of 1 liter of water was 5.34 minutes, the burned biopellet was 124 grams, and the fire color that formed during the combustion was red. The black combustion smoke was just little in intensity and produced at the initial stage of combustion process takes place. The consumption rate was measured for three times. The result of this study showed that the average consumption rate of palm shell biopellet was 1.39 kg/hour that was lower than one of rice husk (1.76 kg/hour) (Rahman, 2011) and higher than the one of jatropha cake (0.63 kg/hour) (Liliana, 2010). This condition was caused by the difference of calorific value of each material of biopellet.

Combustion Efficiency: The main parameter of successful application of biopellet is combustion quality which is measured in terms of combustion efficiency. It is the ratio of the energy needed to boil the water and the energy supplied (containing in the used biopellet) in heating the water. The results of the combustion efficiency test of palm shell biopellet are presented in Table 8.

Table 7. The consumption rate of biopellet

Repetition	Boling time of 1 L of water (minute)	Biopellet mass that used (g)	Consumption rate (kg/hours)
1	5.13	119.00	1.39
2	5.50	125.50	1.37
3	5.40	127.50	1.42
		Average	**1.39**

Table 8. The combustion efficiency of the best formulation of palm shell biopellet

Repetition	Energy to boil 1 L of water (kcal)	The caloric value of biopellet (kcal)	Efficiency (%)
1	75.60	626.64	12.06
2	76.10	660.87	11.52
3	75.10	671.40	11.18
Average	75.43	652.97	11.59

The average energy that was needed to boil one liter of water was 75.43 kcal and the average of the calorific value of biopellet that was used was 652.97 kcal, thus the combustion efficiency of palm shell biopellet was 11.59%. The combustion efficiency of palm shell biopellet was higher than the one of rice husk (9.40%) (Rahman, 2011) and lower than jatropha cake (33.79%) (Liliana, 2010). This was caused by the difference of calorific value of each biopellet. The higher calorific value resulting in better efficiency. In addition, the types of stove also affect the level of efficiency.

Mass Balance

The mass balance analysis in the producing process palm shell biopellet was conducted to determine the yield of each stage of the manufacturing process, starting from milling, screening, carbonizing, mixing, pelletizing, and drying. The simple rule was calculation of the ratio between the mass came (input) and out (output) in each stage of processes at laboratory scale. The amounts 15.86 kg of palm shell were processed yield about 11.54%. The yield of the drying, milling, screening, mixing, densification, and drying was 94.56%, 96.50%, 13.47%, 100%, 79.00%, and 96.00% respectively.

Production Cost

The cost of biopellet production consists of material, operator, electricity, maintenance, milling, and pelletization. It was assumed that there were 21 work days/month and 8 hours of normal working time; production capacity was 1 ton/day; and 5 operators were needed i.e. 2 in transportation, 1 in milling, 1 in carbonization, and 1 people in pelletization. The equipments were hammer mill with 2-3 tone/hour and 7,457 watt, Pellet mill that has specification of 300 kg/hour with 10,000 watt.

The equipment cost of pellet mill, hammer mill, and carbonization device was Rp 130,000,000; Rp 20,000,000; and Rp 10,000,000 respectively. The economic age of each equipment is 20 years, 10 years, and 10 years respectively. The salary was Rp. 700,000/ operator month. The material cost of palm shell was Rp 34,440,000/day. The total operator cost was Rp 3,500,000 per month and the electricity cost was Rp 1,222,808/month. Every equipment has a yearly depreciation cost; Rp 6,175,000 for pellet mill, Rp. 2,700,000 for hammer mill, and Rp 900,000 for carbonization device. Based on these assumption, the unit cost of palm shell biopellet was Rp 1.903/kg.

Comparison to Other Fuels

Palm shell biopellet is a solid state fuel so it may replace wood fire, kerosene, and petroleum gas. The comparison analysis was done to determine the effectiveeness of biopellet as a solid household fuel. The parameters consist of calorific value, effect, and cost of each fuels (Table 9).

There are many positive impacts of using biopellet to replace wood fuel, kerosene and petroleum as listed in Table 9. The main impact of wood fuel that currently facing is deforestation which may potentially be saved by using biopellet. Every hectare of tropical forest stock 109 tons Carbon (Gorte 2009) that can be maintained through application of 53.17 ton of biopellet. Moreover, biopellet has huge capacity to replace the use of kerosene and petroleum gas and save as much as Rp. 6,200 for kerosene and Rp. 1,000 for petroleum gas respectively. Therefore, the use of biopellet should be considered in wider perspective to include economic, social and environmental dimensions.

Table 9. The comparison of palm shell biopellet with other household fuels

Fuels	Parameter		
	Caloric value (kcal/kg)	**The effect**	**Cost (Rp)**
Wood Fuel	3,500	Environmental damage and deforestation	-
Kerosene	10,500	Scarcity of fuel and increasing of the production cost	11,500/liter (not subsidized)
Petroleum Gas in villages	11,500	Difficult to change life style, limited access, distribution cost, and future scarcity	16,000/3 kg
Petroleum Gas in cities	11,500	Demand and price increase	25,000/3 kg
Biopellet	5,265.92	Using 53.17 tones of biopellet can save the trees for 1 hectare, as a substitution of kerosene can save Rp. 6,200, as a substitution of petroleum gas in the villages can save Rp. 1,000 and as a substitution of petroleum gas in the cities is not effective.	3,000/kg

Notes: Saving from substitution of kerosene is Rp (11,500-3000)(10,500/5,265) = Rp 6,262 and from petroleum gas is Rp (16,300/3-3,000)(5,265/11,500) = Rp1,068 (for every kg).

CONCLUSION AND RECOMMENDATION

Conclusion

Utilization of palm shell and palm fiber as raw materials to produce biopellet can improve the calorific value of them for 15.56% of palm shell (4,557.08 kcal/kg to 5,265.92 kcal/kg) and 27.09% of palm fiber (4,048.08 kcal/kg to 5,144.62 kcal/kg).

The addition of palm fiber was significantly different (α=0.05) to the moisture content, ash content, and calorific value. It increased the moisture content and ash content of palm shell biopellet. The addition of palm shell charcoal was significantly different (α = 0.05) to all parameters and reduced the moisture content, ash content, and volatile substances content of palm shell biopellet and increased the fixed carbon content and caloric value. The interaction of addition palm shell charcoal and palm fibers was significantly different (α = 0.05) to the value of volatile matter, fixed carbon content, caloric value, bulk density, and strength pressure. The additions of palm shell charcoal and palm fiber have opposite influence to the bulk density and strength pressure of palm shell biopellet. The bulk density and strength pressure of biopellet decrease with the studied formulation when compared to single formula of 100% of palm shell. However, the combination of formulations could increase the quality of palm shell biopellet by decreasing the moisture, ash, and volatile matter contents and increase the fixed carbon content and caloric value of palm shell biopellet.

The best formulation of palm shell biopellet was the 80% of palm shell and 20% of palm shell charcoal. This formula had the highest calorific value and fixed carbon content and had the lowest moisture, ash, and volatile substance contents. The value of bulk density and strength pressure were also high. The quality of combustion was 1.39 kg/hour and its efficiency was 11.59%. The total yield of producing palm shell biopellet was 11.54%. The unit cost at laboratory scale was Rp 1.903/kg biopellet.

Recommendation

The quality of biopellet might be improved by adding other materials to improve the calorific value of palm shell biopellet while maintaining the bulk density and strength pressure. The level of combustion efficiency might be improved by designing special stove for biopellet. For large scale production, selection of equipment should be based on the detailed analysis of their operating mechanism to improve process efficiency by reducing energy consumption.

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