Effect of Peanut Shell Torrefaction on Qualities of The Produced Bio-pellet

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Abstract

Peanut shells could be regarded as biomass wastes generated from agricultural products, which are abundantly available. The current handling of those wastes is merely through direct incineration, without a proper and controlled manner. Consequently, it could arouse environmental concerns, such as air pollution and human respiratory diseases. One alternative solution is converting those peanut shells to bio-pellet, expectedly applicable for fuels. Relevantly, research on bio-pellet manufacture from peanut shells, previously treated with the torrefaction, was conducted. It's aimed mainly to identify the fuel-related characteristics of bio-pellet products. The tested bio-pellet parameters covered, moisture content, ash content, volatile matters, fixed carbon content, calorific values, and density. The results revealed that torrefaction temperature and time at raw materials (peanut shells) could improve their qualities in regard to particular calorific value compared to those before such torrefaction; which referred to Indonesia's Standard (SNI-8021-2014) for wood bio-pellet. Further, torrefaction could increase bio-pellet quality which satisfied the SNI's Standard, except for ash content. Optimal torrefaction treatment was obtained at 300ºC temperature for 60 minutes, whereby it achieved remarkable bio-pellet characteristics in terms of moisture content (3.092%), ash content (6.116%), volatile matters (38.387%), fixed carbon (55.447%), calorific value (6174 cal/g), and density (0.703 g/cm3). The torrefaction bio-pellets from peanut shells could achieve remarkable performances, with respect to fuel consumption rate (0.68 kg/hr), heating value (6174 kcal/kg), and thermal efficiency (16.67%).

Keywords: *biomass wastes, bio-pellet, conversion, peanut shells, torrefaction treatment*

INTRODUCTION

The increase in human population and concurrently the advancement pace in wood industry have brought concerns on economic growth and depletion of natural energy sources particularly fossil fuels, which cannot be renewed; and hence induced environment pollution. More than 80% of the global energy consumption originates from fossil fuels, which is responsible for the release of greenhouse gases (GHG, including CO_2) and other air pollutants,

causing the changes in atmospheric composition at the global scale. An attempt to reduce those pollutions is through the use of alternative energy sources which are renewable; and employs the so-called clean and green technology which is more environmentally friendly and expectedly able to reduce GHG emission without lowering energy consumption (Shaari *et al.*, 2013; Patel, 2014; Ohlan, 2015). One that could serve as such alternative energy source that prospectively sounds more environmentally friendly is lignocellulose material or the biomass originated from consecutively wood chips, forest products, and estate residues, agriculture wastes, by-product of biomass distillation, and energy-prospective plants, e.g. grasses, animal manure, industrial wastes, settlement residues, municipal solid wastes, algae biomass, and other organic non-food material (Modenbach & Nokes, 2012; Yue *et al.*, 2014; Diego, *et al.*, 2016). Dealing with those biomass wastes through merely direct burning (incineration) without proper or controlled measures can bring about among others air pollution and human respiratory diseases, which are caused by harmful particulates, carbon monoxide (CO), and sulfur dioxide (SO_2) (Laumbach & Kipen, 2013; D'Amato, *et al.*, 2014).

Conversion of biomass material to the better and more usable shapes associated with energy uses could improve their qualities as fuels. In this way, such biomass conversion would facilitate greatly with respect to their handling, transportation, storage, enhancement in burning ability, increases in burning efficiency, more uniform forms, and greater energy density (Tomberlin & Mosey 2013). One of the alternative converted shapes is bio-pellet. Bio-pellets are made up of numerously tiny particles, which previously sustain the intensive size reduction, crushing, and compression at high temperature and pressure for a particular duration. In addition, such bio-pellets could afford better density and sizes than the briquettes as well as their initial/original raw material.

Further, the bio-pellets are useful and more efficient for energy (fuels), as they can increase their energy density and heat capacity per unit volume, thereby generating more heat and hence prolonging burning time as well as achieving higher burning temperature. In this way, those bio-plellet fuels could lower their ash content, exhibit more uniform shapes, afford drier products, and ease for transportation as well as storage (Munawar & Subiyanto, 2014). However, besides such bio-plellet advantages for fuels, there also occur their disadvantages, among others their vulnerable resistance against organism activities, such as fungi and microbes. Those organisms could degrade or decay the organic compounds inside, which are inherently flammable. Also, the bio-pellets with their hygroscopic nature, when stored in high humidity places could increase their moisture content. All those phenomena could lower the calorific value of bio-pellets and hence lower their heating efficiency. Moreover, the spores of fungi might endanger human health and cause human respiratory diseases as well as skin irritation (Graham, 2015).

One of the several ways to overcome or reduce the catastrophic bio-pellet decay or biodegradation is by conducting the so-called torrefaction, which virtually gets the original biomass converted to bio-pellet by adopting the thermochemical treatment. The treatment employs moderately high temperature (200-35ºC) without oxygen or under limited oxygen for relatively short duration range, thereby causing only insignificant biomass weight loss; and also the biomass lignin inside largely intact with minor degradation (Samaniego *et al.*, 2014). The torrefaction treatment aims to improve characteristics of lignocellulose biomass by reducing its oxygen content while concurrently maintaining or minimizing the degradation of oxidation-capable or oxidizable elements inside (with energy release, e.g. carbon and hydrogen), thereby producing fuels with better performance for the combustion as well as gasification process (Medic *et al.*, 2012; Saadon *et al.*, 2014). Likewise, it is expected that the torrefaction could improve the characteristics of bio-pellets exerted from various quality parameters. Several types of research associated with torrefaction treatment on biomass wastes have already been performed. Further, torrefaction on municipal wastes for the manufacture of solid fuels has been conducted by Hardianto *et al.* (2010), whereby optimum condition for the torrefaction was achieved at 250ºC temperature and 25- minute duration. Still related, Chen *et al.*, (2014) performed the torrefaction research on rice husks and examined the characteristics of torrefaction products for fuels. It turned out that the optimum condition for rice husk torrecfaction was achieved at 260ºC temperature and 30-minute duration.

One of the several kinds of biomass wastes abundantly available and potentially usable as bio-plellet is peanut shells. Indonesia's Agency for Statistics Center (2015) recorded that in 2014 the harvested area of peanut plants in Indonesia reached 499,338 hectares and concurrently produced 638,896 tons of peanuts. With approximate potency of peanut shell wastes about 21-29%, it could achieve as much 134,000-185,000 tons of peanut shells as the quantity so far still unutilized. Relevantly, this research aimed as an attempt to utilize the biomass waste of peanut shells, which previously sustained the torrefaction treatment, as raw material for bio-plellet manufacture. The research results are expectedly able to overcome the generation of peanut shells which tend to increase every year and beneficial as fuels.

MATERIALS AND METHODS
Materials

The research was conducted at the Chemical Processing and Energy for Forest Products Laboratory, Forest Products Research and

Development Center, Bogor. The peanut shells ware obtained from Bogor Regency, West Java Province, tapioca starch was obtained from Bogor market, and water.

The equipment is weighing scale, crushing device (disk mill), containers, torrefaction reactor, sieving tools, manual hydraulic compression device, kiln, oven, desiccators, universal testing machine (UTM) apparatus, and bomb calorimeter.

Characterization of Raw Materials

A representative sample of original raw materials (peanut shells) was prepared; and then examined for the chemical analysis in accordance with the particular standard (ASTM, 1977; 1978), which comprised moisture content, ash content, cellulose (ASTM 1103-60-1977), hemicellulose (ASTM-1104-56-1978), and lignin in accordance with the standard (ASTM, 1977).

Methods
Torrefaction Process

The peanut shells were torrefacted at consecutively 250°C, 275°C, and 300°C temperatures, each kept for 30-minute, 45-minute, and 60-minute duration, respectively. The torrecfaction process took place in a horizontally tubular shaped reactor with 10-cm length and 15-cm diameter. At first, a representative sample of peanut shells which weighed 500 grams was prepared and then put into the reactor. Previously, into the empty reactor was flown the inert nitrogen (N_2) at 2 liters-per-minute speed to reduce or drive away oxygen (O2) or other reactive gases from the inside. Subsequently, the temperature was raised to each of those three prearranged temperatures.

When each of the temperatures was achieved, it was held for each of those three prearranged durations. Afterward, the torrefacted sample of peanut shells inside was allowed to cool down, removed from the reactor, and then put into the plastic bags, before being used for further work.

The Process of Biopellet Manufacture

A sample that resulted from the torrefacted peanut-shells was crushed, ground to very small (tiny) size particles, and then sieved such that the particles with 60-mesh size were obtained. The 60-mesh size peanut-shell particles were then added with tapioca starch glue (5%, w/w), and further shaped into bio-pellet using a pellet-molding device with the aid of hydraulic power that employed 2-ton pressure force and 120°C temperature (Figure 1). For the comparison, a sample of peanut shells without torrefaction was also prepared, then also crushed, ground, and sieved in the same way as the sample of torrefacted peanut shells to obtain 60-mesh size untorrefacted peanut shell particles. Those 60-mesh sizes untorrefacted peanut-shell particles also in the same way (including the addition of tapioca starch glue) were shaped into a pellet by employing 2-ton pressure force and 120°C

temperature (Figure 1). In this regard, the shaped product was called control bio-pellet, further used for the comparison. The bio-pellet shaped from either the torrefacted peanut shells or the untorrefacted peanut shells (as control) were tested for particular parameters, which comprised moisture content, volatile matters, ash content, fixed carbon, density, and calorific value. Results of the testes parameters were further compared and referred to the particular standard for wood-converted bio-plellet, under the specification SNI-8021-2014 (Indonesia's National Standard, 2014). In addition, the resulting bio-plellet was also examined for density (Lubis et al., 2016).

Data Analysis

The acquired data associated with particular biopellet characteristics were analyzed using a completely randomized design (CRD) with the factorial pattern. The factors which were employed and assessed comprised consecutively torrefaction temperatures (A) in three levels, i.e. 250°C (a1), 275°C (a2), and 300°C (a3); and torrefaction time/duration (B) in three levels, i.e. 30 minutes (b1), 45 minutes (b2), and 60 minutes (b3), Each of the treatment combination of factors A and B was replicated (R) 3 times. Accordingly, in number there were A * B * R = 3 * 3 * 3 = 27 treatment combinations. The linear additive model with the CRD design was as follows:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \qquad (1)$$

where μ = general mean value; α_i = the effect of factor A (torrefaction temperature) at ith temperature; β_j = the effect of factor B (torrefaction duration) at a jth duration; $(\alpha\beta)_{ij}$ = the effect of interaction between factor A at an ith temperature and factor B at a jth duration; ε_{ijk} = the effect error at ith temperature, jth duration, and kth replication; and Y_{ijk} = the acquired data associated with biopellet characteristics at consecutively ith temperature, jth duration, and kth replication.

If the results of analysis of variance (CRD-based F-test) reveal that the effect of either factor A, factor B, or interaction (A*B) was significant on the data, the then the further analysis proceeded with Duncan's multiple range test (Ott & Longnecker, 2001).

RESULTS AND DISCUSSION
Characteristics of Raw Materials

Characteristics of the original raw materials (peanut shells) were examined, before their torrefaction treatment, which comprised physical-chemical analysis. The analysis results were presented in Table 1. It reveals that the peanut shells used in this experiment were quite dry with their average moisture content (MC) equal to 9.755%. The MC value of raw materials could affect their calorific values, whereby the higher the MC, then the lower would be the calorific value; and conversely for the reverse.

Table 1. Physical-chemical characteristics of peanut shells

Characteristic parameters	Values (%)
Moisture content	9.755
Ash content	3.467
Cellulose	45.010
Hemicellulose	26.812
Lignin	33.600

Further, the high MC of original peanut shells could lower the calorific values of their biopellet products (Unpinit et al., 2015).

The ash content of peanut shells corresponded to 3.467% (Table 1). This ash content value was lower than the value that resulted from the research conducted by Lubis et al. (2016), which reached 6.24%. Ash materials typified as residues, which left behind after complete combustion of organic stuff or biomass (including peanut shells). Such residues were composed almost entirely of inorganic elements, which could cause the formation of deposits that stuck to the metal parts of boilers, burning stoves, and other heating devices, thereby slowing down the heat transfer and hence lowering their heating/burning efficiency. Accordingly, such heating devices necessitated the cleaning work quite frequently (Tarasov et al., 2013). Further, regarding the peanut shells as the common case for residues of agriculture products; their ash content was composed of a predominantly silica element, whereby the higher their silica content, then the higher would be their ash content. Consequently, not only could the presence of high silica in biomass stuff lower the burning efficiency of the stoves during the biomass combustion, but it also caused the dulling action to the related metal tools rapidly (Haygreen et al., 2003; Lukmandaru & Hidayah, 2017).

Cellulose content in peanut shells used for this research experiment corresponded to 45.010%. Cellulose typified as a long-chained polymer which originated from nature and served as a principal constituent in the cell wall of plant biomass. The cellulose content in biomass stuff (including the peanut shells) apparently did not affect many their calorific values, rather it was the lignin content that did considerably to those values. Further, Putra *et al.* (2013) asserted that although cellulose content in biomass was generally higher than lignin content, in fact, the role of lignin in affecting or determining the calorific values of biomass was greater than the role of cellulose. In other words, the variation of lignin content in biomass stuff determined changes in their calorific values more strongly than the comparative variation of cellulose content. This is because the content of carbon (C, as the main oxidizable element in biomass) in lignin was greater than the content in cellulose, i.e. 67.50% and 44.44%, respectively (Sjostrom, 1993). Hemicellulose content in peanut shells corresponded to 26.81%. In determining the hemicellulose content in biomass, it was obtained by

subtracting the holocellulose content with alpha-cellulose content. Mazlan *et al.*, (2015) stated that hemicellulose was degraded easier or faster than cellulose or lignin. This is because hemicellulose is also a polymer but with a shorter chain, constituted of amorphous structure inside the biomass cell wall, and rich in a branch-chained arrangement in its bond structure. Consequently, the heat stability of hemicellulose is lower than that of cellulose, which consisted of longer straight-chained polymer (without branches). Regarding the lignin, its content in the peanut shells for this experiment was 33.60%. Lignin is a three-dimensional polymer that also constitutes a biomass cell wall, besides cellulose and hemicellulose. Lignin also served as a binding agent that held or cemented the cells together. Accordingly, the lignin expectedly could also function as a natural binder, which could be utilized in this biopellet manufacture. Further, as described before, lignin contained more carbon atoms than cellulose and hemicellulose (Putra, *et al.*, 2013). Also as depicted before, Bhavanam & Sastry (2011) stated that the number of carbon atom affected the content of fixed carbon in a material (including biomass stuff). Therefore, the higher the fixed carbon content in materials, then the higher would be their calorific values and hence their heat as evolved.

Characteristics of Bio-pellet Products

Figure 1 presents the surface-color of peanut shells after being air-dried and then torrefacted. Visually, the shell surface of original or untorrefacted peanuts revealed their yellowish color. Further, it could be seen that increasing the torrefaction temperature at peanut shells brought about significant gradual changes in their skin surface color from yellowish (untorrefacted) to blackish brown color (torrefacted). After the manufacture of bio-pelllet from both untorrefacted (control) and torrecfacted peanut shells, it appeared the visual changes in their own shell surface. For the untorrefacted peanuts, their skin changed from yellowish to brownish color (Figure 1a), possibly due to physical contact between their shell surface and bio-pellet-molding metal device during the application of 2-ton pressing force, coupled concurrently with the exertion of 200ºC heat. Likewise, in the same way for the torrefacted peanut shells, their shell surface also changed, but from blackish brown to charcoal-black color (Figures 1b, 1c, 1d). Color changes for the latter could occur brought about by chemical changes inside the torrefacted peanut shells during the torrefaction heating, such as changes in components, amino acids, and possibly the formation of the aromatic ring system associated with aromatization and polycondensation reactions (Samaniego *et al.*, 2014).

Qualities of Bio-plellet

Such qualities are associated with testing results on their physical, chemical and mechanical properties
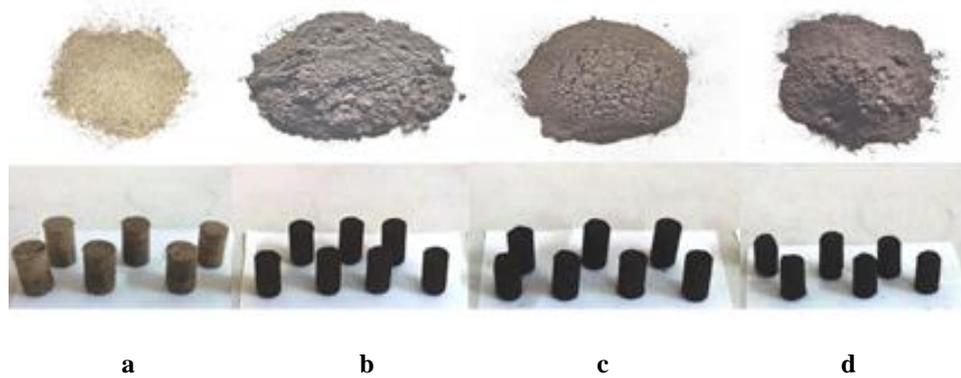
Figure 1. Visual appearances of peanut shells (above) and the produced bio-pellets (below); (a) without torrefaction (b); torrefaction at 250ºC; (c) torrefaction at 275ºC; and (d) torrefaction at 300ºC

Table 2. Analysis of variance on characteristics of bio-pellet manufactured from the torrefacted peanut shells

Variable	Moisture content		Ash content		Volatile matter content		Fixed carbon content		Calorific value		Density	
	F	P	F	P	F	P	F	P	F	P	F	P
A	4.64	0.02	1378.35	0.00	656.49	0.00	496.67	0.00	26.69	0.00	15.55	0.00
B	4.45	0.02	506.91	0.00	66.10	0.00	33.89	0.00	11.50	0.00	1.05	0.37
A*B	0.739	0.58	39.99	0.00	13.87	0.00	9.52	0.00	0.80	0.54	1.39	0.28

Remarks: A = Torrefaction temperature; B = Torrefraction time (duration); A*B = interaction of A and B factors
F = F- calculated P = P-value (<0.05)

Table 3. Characteristics of bio-pellets shaped from either untorrefacted (control) or torrefacted peanut shells

Treatment	Characteristics					
	Moisture content	Ash content	Volatile matter content	Fixed carbon content	Calorific value	Density
	%	%	%	%	cal/g	g/cm^3
Control	5.102	4.759	75.576	19.665	4488	0.865
A$_1$B$_1$	4.645 cd	2.772 a	60.132 ef	37.145 a	5431 a	0.802 cdef
A$_1$B$_2$	3.917 bcd	3.564 b	58.608 ef	37.828 ab	5547 ab	0.805 cdefg
A$_1$B$_3$	3.529 ab	3.711 b	58.258 de	38.031 ab	5590 ab	0.827 defg
A$_2$B$_1$	3.776 bc	4.367 c	56.619 d	39.014 b	5571 ab	0.799 cde
A$_2$B$_2$	3.646 ab	5.615 f	50.383 c	44.003 c	5732 bc	0.769 cd
A$_2$B$_3$	3.557 ab	6.006 g	49.395 c	44.538 c	5858 c	0.761 bc
A$_3$B$_1$	3.693 ab	4.704 d	45.020 b	50.276 d	5754 bc	0.710 ab
A$_3$B$_2$	3.308 ab	4.954 e	44.171 b	50.875 d	5960 cd	0.703 a
A$_3$B$_3$	3.092 a	6.116 g	38.387 a	55.447 e	6174 d	0.757 abc
SNI 8021:2014*)	Max. 12	Max. 1,5	Max. 80	Min. 14	Min. 4000	Min. 0,8

of bio-pellet shaped from either untorrefacted (control) or torrefacted peanut shells (Tables 2,3, and Figure 1).

Moisture content

Moisture content (MC) of the bio-pellet shaped from the torrefacted peanut shells ranged about 3.092-4.645% (Table 3). Minimum MC (3.092%) was obtained at bio-pellet that resulted from the torrefaction at 300ºC for 60 minutes (duration), while maximum MC was from the torrefaction at 250ºC for 30 minutes. Results of analysis of variance (ANOVA, Table 2) disclosed that the torrefaction temperature (A) and duration (B), as well as their interaction (AB), brought about the significant effect (p<0.05) on bio-pellet MC. Further analysis with Duncan's multiple range test (DMRT, at p<0.05) indicated that both

increasing torrefaction temperature and prolonging torrefaction duration tended to decrease the bio-pelllet MC (Table 3). This is because such temperature increase (250-300ºC) and duration prolongation (30-60 minutes) caused the water inside the torrefacted peanut shells to evaporate out more intensively into the surrounding air, thereby decreasing the MC of the produced bio-pellet.

Results of DMRT test revealed that the MC of bio-pellet shaped from the torrefacted peanut shells under the torrefaction temperature at 300ºC for 60 minute duration did not differ significantly from the MC under the temperature at consecutively 300ºC for 45 and 30 minutes; 275ºC for 60 and 45 minutes; 250ºC for 60 minutes; but significantly different from the MC under other treatment combinations (AB) of torrefaction temperature (A) and duration (B) (Table

3). Further, compared to the MC of control bio-pellet (without torrefaction), all the MC's of bio-pellet from the torrefacted peanut shells were lower (Table 3). This could be understood that again the use of such high temperature and longer duration in the torrefaction caused the more intensive evaporation of water in the torrefacted peanut shells than the evaporation in untorrefacted peanut shells, thereby bringing out the higher MC in the corresponding produced bio-pellet

The MC's of bio-pellet that resulted in this research (3.092-4.645%) were almost similar to the MC in bio-pellet manufactured from the mixture of torrefacted peanut shells (40%), sugarcane's bagasse (50%), and original/untorrefacted peanut shells (10%), which varied about 3.44-3.85% (Lubis *et al*., 2016). The slightly higher MC's of bio-pellet obtained in this research compared to MC of Lubis' experiment possibly due to the addition of tapioca starch as the binder for bio-pellet manufacture, which exhibited hygroscopic (water-attracting) characteristics. However, all the research's MC could still meet the standard requirement stipulated by SNI 8021:2014 (maximum 12% MC).

Ash content

Ash content in bio-pellet from the torrefacted peanut shell ranged about 2.772-6.116% (Table 3). The lowest ash content was obtained in bio-pellet that resulted from the torrefaction temperature at 250°C for 30-minute duration, while the highest content was from the temperature at 200°C for 60 minutes. Anova results (Table 2) revealed that the effect of torrefaction temperature and duration together with their interaction was significant ($p<0.05$) on ash content. Further, based on the DMRT test ($p<0.05$), increases in both torrefaction temperature and duration tended to decrease the ash content (Table 3). The increasing temperature and duration possibly rendered the partial degradation of organic matters inside the torrefacted peanut shells, while the inorganic compounds (ash) remained practically unaffected or intact. Further DMRT test revealed that the ash content in bio-pellet shaped from the torrefacted peanut shells at 250°C temperature for 45 minutes differed significantly from the content obtained under other treatment combinations of AB (Table 3).

Ash content in biomass (including peanut shells) was affected by the content of mineral elements inside and growth location of their host plants (Lukmandaru & Hidayah 2017). All ash content in bio-pellet from the torrefacted peanut shells in this research (2.772-6.116%) was lower than the content in bio-plellet that resulted from the experiment by Lubis *et al*. (2016), which varied about 7.34-9.10%. However, all the ash content in the research's bio-pellet was entirely higher than the content stipulated by SNI 8021:2014 (maximum 1.2% ash content). Such high ash content could be attributed to the addition of

tapioca starch to the binder, which could also contain mineral elements.

Volatile matters

Volatile matter content of the bio-pellet from the torrefacted peanut shells ranged about 38.87-60.132% (Table 3). The lowest volatile matter content was obtained at 300°C temperature for 60-minute duration, while the highest content at 250°C temperature for 30 minutes. Based on anova (Table 2) and DMRT results (Table 3), there occurred a trend that increasing torrrefaction temperature and prolonging torrefaction time (duration) at peanut shells brought about the decrease in volatile matter content in the produced bio-pellet. The possible explanation was that the higher the torrefaction temperature as well as the longer the torrefaction duration, the more intensive would be the volatilization of organic compounds particularly the extractives as well as the shell's organic compounds with simple structure and low molecular weight, thereby leaving behind the more resistant organic compounds that could withstand high temperature (maximum 950°C for 6 minutes, procedure prevalently used for the determination of volatile matters) and hence lowering the volatile matters content in the produced bio-pellet, this is in accordance with research by Rajnai et al. (2017).

All the volatile matter contents of the bio-pellet with torrefaction treatment (38.87-50.13%) could comply with the standard under the specification set forth by SNI 8021:2014 (Indonesia's National Standard 2014) which mentioned maximum 80% volatile matter content (Table 3). Further, the volatile matter content in the control bio-pellet (75.57%) was much higher than the overall contents in the (research) bio-pellet with torrefaction (Table 3). This again confirmed that the totrrefaction could lower the volatile matter content. This occurrence was commensurate with research results by Samaniego *et al*. (2014), who asserted that torrefaction treatment could decrease the volatile matter content in ponderosa pine from 77.73% (before torrefaction) to 34.66% using the torrefaction temperature at a 175-350°C range, with a 25°C interval. Mitchell *et al*. (2016) alleged that organic stuff with high volatile matter content on combustion could bring about the evolvement of thick and black-colored smoke.

Further assessment using Duncan's multiple range test (Table 3) with $p<0.05$ revealed that the volatile matter content in bio-pellet shaped from peanut shells torrefacted in 300°C for 30-minute duration was significantly different from the one torrefacted at 300°C for 45 minutes. Likewise, the volatile content that resulted from the torreaction at 275°C for 45 minutes did not differ significantly either from the one at 275°C for 60 minutes. Meanwhile, the volatile matter content in bio-pellet from peanut shells torrefacted at 300°C for 60 minutes was the lowest and did not significantly differ from the content at other treatment combinations (AB) of torrefaction

temperature (A) and time (B). The overall volatile matter contents of the research bio-pellet (38.87-50.13%) ware lower than the content in oil-palm shells (55.34-72.38%) (Bantacut *et al.*, 2013).

Fixed carbon content

The values of fixed carbon content in bio-pellet shaped from the torrefacted peanut shells varied about 37.145-55.447% (Table 3). The lowest value was obtained in bio-pellet from peanut shells torrefacted at 250°C for 30 minutes, whereas the highest values obtained at 300°C torrefaction temperature for 60 minutes. All the fixed carbon contents in this research (37.145-55.447%) could remarkably favor the requirement by SNI 8021:2014, which mentioned a minimum 14% fixed carbon content. In the control bio-pellet, its fixed carbon content reached 19.49%, which was much lower compared to the content in bio-pellet shaped from torrefacted peanut shell (37.145-55.447%). This again confirmed that torrefaction on peanut shells could increase the fixed carbon content in the produced bio-pellet. Further, the fixed carbon contents in the research bio-pellet (37.145-55.447%) were also much higher than the content in oil-palm shells (13.40-34.85%) (Bantacut *et al.*, 2013).

Results of anova (Table 2) disclosed that torrefaction temperature and duration, as well as their interaction, brought about the significant effect ($p<0.05$) on fixed carbon content. Further analysis with the DMRT test (Table 3) revealed that the increasing torrefaction temperature as well as prolonging torrefaction duration at peanut shells tended to increase the fixed carbon content in the produced bio-pellet. This could be explained that with such increasing/prolonging, it caused more extractive matters as well as non-carbon compounds or more carbon compounds, but with low molecular to be evaporated, volatilized or degraded, thereby leaving behind the carbon elements strongly bonded to other carbon or to other kinds of elements in the peanut shells that could withstand high temperature (maximum 950°C for 6 minutes, procedure prevalently used for the determination of fixed carbon) and hence increasing the fixed carbon content in the produced bio-pellet (Lubis *et al.*, 2016). This occurrence was also in conformity to the research results by Tumuluru (2016), who asserted that torrefaction treatment of pine wood at 160°C to 180°C both for 30 minutes caused the increase in its fixed carbon content of pine wood, beginning from 52.23% to 56-75%.

Meanwhile, correspondingly increasing temperature to 230-270°C for 120 minutes rendered the fixed carbon content in pine wood to increase from 62% to 68%. Results of DMRT test also revealed high fixed carbon content in bio-pellet occurred in bio-pellet that resulted from implementing torrefaction temperature at 300°C for 60 minutes, which were significantly different from the content in bio-pellet that implemented different values of torrefaction temperatures and durations (Table 3).

Calorific value

The calorific value of bio-pellet shaped from the torrefacted peanut shells varied about 5431-6174 cal/g (Table 3). The lowest calorific value was obtained using torrefaction temperature at 250°C for 30 minutes, while the highest occurred at implementing as high 300°C as torrefaction temperature for 60 minutes. The calorific values of these research bio-pellets could comply with the specification of SNI-8021:2014 (Indonesia's National Standard, 2014), which specified a minimum 4000 cal/g. Further, the calorific values as obtained in this research was better (higher) than the values for Japanese cedar wood pellet (4995.22-5497.13 cal/g), which implemented the torrefaction temperature range at 170-260°C with changes as much 20°C as a temperature interval (Yoshida *et al.* 2015).

Results of anova revealed that torrefaction temperature and duration at peanut shells as well as their interaction affected significantly (Table 2) the calorific value of the produced bio-pellet. Further assessment using DMRT test (Table 3) pointed out that implementing torrefaction temperature at 300°C for 60 minutes brought out bio-pellet with the highest calorific value, which was not significantly different from the values that implemented also the temperature at 300°C but for 45 minutes. However, such higher value significantly differed from the values by implementing different torrefaction temperatures as well as different torrefaction duration. Meanwhile, the calorific value by implementing torrefaction temperature at 300°C for 45 minutes was not significantly different from the values that implemented torrefaction temperature at consecutively 300°C for 45 minutes, 275°C for 60 minutes, and 275°C for 45 minutes. The latter situation implied that torrefaction temperatures and duration were interdependent, whereby increasing temperature could be compensated by shortening the duration in particular range; and conversely for the reverse such that it yielded the bio-pellets with about similar or insignificantly-different calorific values.

Table 3 further disclosed that the calorific value of the control bio-pellet (4488 cal/g) was lower than the values of the research bio-pellet (with torrefaction treatment), which ranged about 5431-6174 cal/g. This strongly confirmed that the torrefaction treatment of original raw material (peanut shells) could increase calorific values of the produced bio-pellets. Further, these research results were commensurate with the results by Keipi *et al.* (2014), who alleged that the torrefaction on biomass stuff at 260°C for 60 minutes could increase their calorific values from 4660.61-5019.12 cal/g to 5066.82-5544.93 cal/g.

Results of DMRT test (Table 3) also hinted that increasing torrefaction temperature as well as prolonging its duration at peanut shells tended to increase the calorific values of the produced bio-pellet. These trend changes in calorific values also occurred almost in a similar pattern to the changes in fixed

carbon content of the research bio-pellet. These phenomena were also similar to the case of lower calorific value (4488 cal/g) and concurrently lower fixed carbon content (19.665%) of the control bio-pellet than the value (5431-6174 cal/g) and the content (37.145-55.447%) of the torrefacted bio-pellet; and therefore such phenomena could be understood, because the calorific value of carbon-containing stuff (including peanut-shell bio-pellet) correlated positively and strongly with their fixed carbon content. In other words, the high calorific value of stuff was strongly affected by their high fixed carbon content. Accordingly, the material that contains high fixed carbon would on burning release energy (heat) with high calorific value (Hendra, 2011; Unpinit *et al*., 2015). Moreover, the higher the calorific value of fuel materials, the better would be their burning/combusting ability or qualities; and on the contrary for the reverse.

Density

The density of bio-pellet shaped from the torrefacted peanut shells ranged about 0.703-0.827 g/cm^2 (Tabel 3). The highest density was obtained using torrefaction temperature at 250°C for 60 minutes (0.827 g/cm^2), while the lowest occurred in implementing 300°C torrefaction temperature for 45 minutes (0.703 g/cm^2).

Anova results revealed that torrefaction temperature (A) and duration (B) at peanut shells as well as their interaction (AB) brought about the significant effect on bio-pellet density (Table 2). Further analysis using DMRT test disclosed that combination of torrefaction temperature and duration which brought out highest bio-pellet density (0.827 $g.cm^3$) did not differ significantly from the density of bio-pellet that implemented the particular four treatment combinations (AB) of torrefaction temperatures (A) at consecutively 250°C for 30 minutes (B), 250°C for 45 minutes, 275°C for 30 minutes, and 275°C for 45-minute duration. However, such highest bio-pellet density was significantly different from the density obtained from implementing those four combinations (AB).

Meanwhile, the density values of control bio-pellet (0.865 $g.cm^3$) ware higher than the values of the torrified bio-pellet (0.703-0.827 g/cm^2). The possible explanation was that the hemicellulose, cellulose, and lignin in initial raw material (peanut shells) were still intact. However, at high temperature during the torrefaction (250-300°C), the hemicellulose and cellulose in peanut shells became more severely degraded than the lignin, as the latter was more heat resistant than the former (Haygreen et al. 2003). Such degradation possibly brought about a creation of fragile or less compact structures partially inside the cell wall of peanut shells, thereby rendering the wall less dense (less compact) and consequently lowering the density of the produced bio-pellets from the torrefacted peanut shells. On the other hand, such still intact lignin in the raw or untorrefacted peanut shells besides imparting rigidity of their cell wall caused the lignin ability to bond together peanut shell pieces (particles) to become more intensive during the shaping of control bio-pellet, thereby augmenting their density (Table 3).

The density of bio-pellet was also affected by dimensions (sizes) of peanut shell particles that shaped bio-pellet, whereby particles with coarse (larger) sizes would bring out bio-pellet products with low density (Munawar & Subiyanto 2014). In addition, the strength of compressing pressure and hole diameter of the bio-pellet molding/shaping device could also affect the bio-pellet density, in that the greater the pressure and the smaller the hole diameter, then the greater would be the bio-pellet density; and conversely for the reverse (Macak *et al*., 2015). The densities of these research bio-pellets (0.703-0.827 g/cm^2) were almost similar to densities of bio-pellet shaped from empty oil-palm bunches (0.77-0.81 g/cm^3), which were hot-pressed at 150-250°C (Munawar & Subiyanto, 2014).

The research result revealed that some quality of bio-pellet i.e moisture content, volatile matters, fixed carbon content and calorific value could satisfy Indonesia's National Standard (SNI 0821:2014). Meanwhile, the density of bio-pellet shaped from the torrefacted peanut shells only partly could satisfy the standard stipulated by SNI 8021:2014 (Indonesia's National Standard, 2014), which were obtained from treatment that implemented temperature at 250°C for consecutively 30, 45, and 60 minutes. Also, in ash content, all the implemented treatment combination could not meet the SNI.

Characteristics of Bio-pellet Combustion
Consumption rate

It is essential to look into the combustion characteristics of bio-pellet shaped from either the torrefacted or untorrefacted peanut shells (control). Those characteristics pertained to among others the consumption rate of bio-pellet for the combustion purposes. Such consumption rate was calculated by measuring the weight of bio-pellet mass which was used up or burnt; and the weight of the remaining bio-pellet mass which was not used up (not burnt), which implemented the so-called method of water-boiling test (Belonio, 2005). The results of the experimental research revealed that it took the average time as long as 8.9 minutes to boil one liter of water through the combustion of control bio-pellet. As such, as much as 117.0 grams of the initial weight of the control bio-pellet were burnt; and the bio-pellet consumption rate reached 0.79 kg/hour (Table 4). Likewise, in the same way, it took average time as long as 6.8 minutes to boil also one liter of water by combusting the bio-pellet shaped from the torrefacted peanut shells at 300°C temperature for a 60-minute duration (Table 3).

Table 4. Combustion characteristics of the produced bio-pellets

Characteristic	Bio-pellet	
	Control	(A_3B_3) [**]
Boiling time of 1 L of water (minute)	8.9	6.8
The biopellet fuel used up on burning, g	117	77
Fuel consumtion rate (FCR), kg/hr	0.79	0.68
Heating value of fuel (HVF), kcal/kg	4488	6174
Thermal efficiency, %	14.86	16.67

[*] In oven dry weight
[**] Please refer to Table 3

As such, also, in the same way, 77.6 grams of the same initial weight of torrefacted bio-pellet under particular treatment combination (A_3B_3) of torrefaction temperature and its duration (Table 4) were burnt; and the bio-pellet consumption rate corresponded to 0.67 kg/hour.

Such high consumption of the control bio-pellet could possibly be attributed to its high volatile matter content (75.58%) compared to content in bio-pellet but with the torrefacted peanut shells (38.79%) (Table 3). These phenomena were in conformity to the statement by (Sulistyanto, 2006), who reported that the consumption rate of bio-briquette fuels could be positively affected by their volatile content. As such, the higher the volatile matter content in bio-briquette or bio-pellet fuels, then the easier or more flammable would be those fuels to burn; and hence the faster would be their burning rate. In this regard, the volatile matters functioned only as a starter (igniter) to get the bio-pellets easily burnt in their initial combustion.

The thermal efficiency

Results of analysis on thermal efficiency accomplished by bio-pellet that used biomass stove are presented in Table 4. Thermal efficiency in term of scientific definition implied the ratio between the amount of energy used by the fuels in boiling and evaporating water and the amount of available energy in such fuels, including the bio-briquette and bio-pellet (Belonio 2005). Referring to these research results, the bio-pellets shaped from peanut shells without torrefaction treatment (control) afforded the thermal (combustion) efficiency (14.86%), which was lower than the efficiency performed by bio-pellets shaped from the torrefacted peanut shells (16.67%). This strongly suggested that the torrefaction on original raw materials (peanut shells) could enhance the thermal efficiency of the produced bio-pellet. The thermal efficiency of bio-pellet achieved in this research (16.67%) was still slightly lower than the efficiency of bio-pellet manufactured from the combined mixture comprising oil-palm shell charcoal (20%) and oil-palm fibers (11.59%) (Bantacut et al., 2013). Thermal efficiency was also affected by the shapes of the original raw materials when being fed to the stoves. Raw materials in bulk form or without densification in general afforded thermal efficiency, which was lower than the materials with the densification, such as bio-pellet. In addition, thermal efficiency was affected as well by the stove type or model which was used (Belonio 2005).

CONCLUSIONS

Peanut shells as biomass wastes could indicatively be utilized as raw material for an alternative energy source (fuel) through their conversion into bio-pellets. Those bio-pellets products were shaped from the torrefacted peanut shells. In general, the qualities of those torrefacted bio-pellets could satisfy the requirements stipulated by Indonesia's National Standard (SNI-8021:2014) associated with wood bio-pellets.

The best qualities of the torrefacted bio-pellets were obtained the torrefication treatment of the raw material (peanut shells) that implemented temperature at 300ºC for a 60-minute duration. As such, those torrefacted bio-pellets achieved particular values of consecutively moisture content (3.092%), ash content (6.116%), volatile matter content (38.387%), fixed carbon content (55.447%), calorific value (6174 cal/g), density (0.703 g/cm^3). To be used as fuel, those torrefacted bio-pellets could achieve remarkable performances, with respect to fuel consumption rate (0.68 kg/hr), fuel's heating value (6174 kcal/kg), and thermal efficiency (16.67%).

As such, as fuel, those torrefacted bio-pellets afforded several superiorities compared to performances of control bio-pellets (shaped from the original/untorrefacted peanut shells) in term of among others: greater fuel's heating value, less amount of fuel consumption rate, and greater thermal efficiency.

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