**Jurnal Presipitasi**
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 20, No 1, 2023, 165-174
Article available at homepage presipitasi

*Original Research Article*

# Optimizing Utilization of Hazardous Waste and Biomass as Solid Fuel for Co-Firing

**Fandy Ahmad Fauzy[1], Etih Hartanti[1]*, Dyah Marganingrum[2]**
[1]Environmental Engineering Study Program, Faculty of Civil Engineering and Planning, Institut Teknologi Nasional, Jalan P. H. H. Mustofa No. 23, Bandung, Indonesia 40124
[2]National Research and Innovation Agency (BRIN), Jalan Cisitu Lama No. 12, Bandung, Indonesia 40135
*Corresponding Author, email: etih@itenas.ac.id

## Abstract
Continuously high use of fossil fuels may lead scarcity of these energy sources in the future. Therefore, it is necessary to develop renewable energy to ensure its availability. One of the efforts in the development of renewable energy and the aims of this study is to examine the utilization Fly Ash (FA), Bottom Ash (BA) combined biomass sludge of Wastewater Treatment Plant (WWTP) and municipal solid waste) materials as an alternative energy source (briquette raw materials) for co-firing in textile industry boilers. Briquettes were made with a composition of 60% FABA and 40% biomass which were then varied in composition. The parameters measured were proximate, calorific value, and shatter index. The feasibility test of briquettes was carried out using a Tanner diagram, where all briquettes made can be burned as fuel. Optimum briquettes quality was measured based on the criteria according to the Minister of Environment and Forestry Regulation No. 06/2021. The results showed that the composition of three briquettes that had optimum quality and met the criteria were briquettes with composition 10%FA:50%BA:40%Biomass (variation of WWTP sludge and biomass) with a calorific value and sulfur content of 3,578 Kcal/kg and 0,70%; 3,890 Kcal/kg and 0,82%; and 3,864 Kcal/kg and 0,96%.

**Keywords**: Biomass; bottom ash; briquettes; fly ash; sludge

## 1. Introduction

Indonesia is a country that has the highest level of energy consumption in the Southeast Asia region, where energy consumption is dominated by the consumption of fossil energy. Every year, energy use continues to increase, but this increase is not accompanied by available energy sources to support this energy consumption. The high use of fossil fuels continuously raises concerns about the future scarcity and even exhaustion of these energy sources. Therefore, to avoid the scarcity of energy sources, it is necessary to develop renewable energy so that the sustainability and availability of energy can be continuously fulfilled (Afriyanti et al., 2020).

One of the efforts in developing renewable energy is the use of biomass and hazardous waste as alternative energy sources. Biomass is a renewable energy source composed of biological materials. In general, biomass is a material that can be obtained from living things and used in large quantities. Biomass specifically refers to agricultural waste, forestry waste, animal manure, kitchen waste, and others (Yokoyama & Matsumura, 2008). Meanwhile, B3 waste is the residue of a business and/or activity that contains B3, which may be utilized to become a product that can be used as a substitute for raw materials, auxiliary materials, and/or fuel that is safe for human health and the environment (PerMen LHK 18/2020).

According to Minister of Environment and Forestry Regulation No. 06 of 2021 (PerMen LHK 06/2021), the utilization of B3 waste must be carried out by activities that produce B3 waste. One type or category of B3 waste includes sludge by-products produced from the Wastewater Treatment Plant (WWTP) and coal ash (bottom ash and fly ash/FABA). In industrial activities that continue to operate, these two wastes can accumulate and if not managed will cause problems for the environment. Previous studies have utilized FABA and textile WWTP sludge as solid fuel in the form of briquettes with a mixture of biomass from processed municipal solid waste (MSW) (Marganingrum et al., 2020; Rahmaulina et al., 2022).

Briquettes are one of the solid fuel products with high density through the process of using pressure on the particle mass. Briquettes made from organic materials can be called bio-briquettes. Biobriquettes are alternative fuels made from residual organic materials with a mixture of adhesives and have a certain compressive strength (Yustanti, et al, 2022). The utilization of FABA, WWTP sludge, and biomass into briquettes has been widely carried out in Indonesia, including briquettes made from a mixture of bottom ash from Electric steam power plant and biomass from carbonized teak leaves which produce a calorific value of 2,985 Kcal/kg (Indriyani et al., 2015), briquettes made from a mixture of bottom ash and biomass made from municipal solid waste which produces a calorific value of 3,374 Kcal/kg (Marganingrum et al., 2020), and the manufacture of briquettes from a mixture of bottom ash and sludge from WWTP of textile industry which produces a calorific value of 1,473 Kcal/kg (Rahmaulina et al., 2022). However, these three studies did not make briquettes with a mixture of fly ash, which is produced from the process of burning coal in boilers. From various studies on the utilization of fly ash, not many studies have discussed the utilization of fly ash as one of the raw materials for briquettes, usually fly ash is used for road construction, embankments, building materials, geopolymer applications, and cement production (in the field of civil engineering), so it is necessary to conduct research on briquettes to be used as a companion fuel with a mixture of raw materials, namely fly ash and bottom ash (FABA), WWTP sludge, and biomass from fermented urban waste (Marganingrum et al., 2021).

Therefore, in this research, a study was conducted on the characteristics of briquettes made from WWTP sludge and FABA from PT X, one of the textile industries in Bandung Regency, and the last raw material was biomass from fermented municipal solid waste. The purpose of this study is to identify the quality of briquettes that meet the criteria PerMen LHK 06/2021 and the provisions of the Tanner diagram as a basis for assessing the feasibility of these briquettes as co-firing fuel.

## 2. Methods

This research was conducted at the Laboratory of the Center for Environmental Research and Clean Technology, National Research and Innovation Agency (BRIN), Bandung. The raw materials used for the manufacture of briquettes are FABA and WWTP sludge from PT X Bandung Regency, as well as biomass from fermented municipal waste. The stages of this research consisted of sample preparation of briquette raw materials by conducting initial characterization of the parameters of moisture content, volatile content, ash content, fixed carbon (proximate analysis), calorific value, and sulfur content. Then proceed with the manufacture of briquettes based on the composition variations in Table 1. Furthermore, characterization of the briquettes that have been made is carried out again, and then testing the shatter index to determine the strength of the briquettes against impact. The characteristics of the raw materials and briquette products were compared with criteria of PerMen LHK 06/2021 to determine their quality.

### 2.1. Making Briquettes

Briquettes are made from a mixture of the four raw materials with variations in milk composition according to Table 1, and mixed with an adhesive material in the form of tapioca starch (amylum) which is thickened beforehand using water with the ratio of amylum and water is 1:10 (Marganingrum et al., 2021). The adhesive used was tapioca starch (organic adhesive) as much as 5% of the total weight of raw materials to be made into briquettes. The mixture of raw materials needed to become one briquette is 50 grams. There are three formulas made where the briquette variation is written with the code '**F.numbers.lowercase letters**' (example: F.1.a). '**F**' means formula, followed by the code '**number**' which means the nth formula and describes the percentage difference in weight of the WWTP sludge and Biomass samples used, and the last code is '**lowercase letters**' which is used to describe the percentage difference in weight of FABA used. The process of molding raw materials into briquette products is carried out using molds and hydraulic press tools. Then, the raw materials are molded and pressed for 5-8 minutes to make 12 briquettes from each briquette formula.

**Table 1.** Variation of briquette composition

| **Sample Code** | **Coal ash (FABA) (60%)** | | **Biomass (40%)** | |
|---|---|---|---|---|
| | **Bottom Ash (%)** | **Fly Ash (%)** | **WWTP Sludge (%)** | **MSW Fermented (%)** |
| F.1.a | 30 | 30 | 10 | 30 |
| F.1.b | 40 | 20 | | |
| F.1.c | 50 | 10 | | |
| F.1.d | 20 | 40 | | |
| F.1.e | 10 | 50 | | |
| F.2.a | 30 | 30 | 20 | 20 |
| F.2.b | 40 | 20 | | |
| F.2.c | 50 | 10 | | |
| F.2.d | 20 | 40 | | |
| F.2.e | 10 | 50 | | |
| F.3.a | 30 | 30 | 30 | 10 |
| F.3.b | 40 | 20 | | |
| F.3.c | 50 | 10 | | |
| F.3.d | 20 | 40 | | |
| F.3.e | 10 | 50 | | |

### 2.2. Characterization of Briquette Raw Materials and Briquette Products

The characterization of raw materials and briquette products was carried out on proximate analysis (moisture content, volatile content, ash content, and fixed carbon) using a Thermogravimetric Analyzer with the ASTM D5142 Moisture Volatile Ash standard method. Furthermore, measurements were made of the calorific value of the raw materials and briquette products that had been made using a bomb calorimeter with the ASTM D5865 Gross Calorific Value of Coal and Coke standard method. Then the last analysis is the sulfur content parameter of briquette products using the Eschka-gravimetric method. The following calculation formula is used in the measurement of proximate parameters and calorific value:

- Calculation of Moisture Content

$$\%\,moisture\ content = \frac{initial\ sample\ mass - mass\ of\ moisture\ content}{initial\ sample\ mass} \times 100\% \quad (1)$$

- Calculation of Volatile Matter

$$\%\,Volatile\ matter = \frac{mass\ of\ moisture\ content - mass\ of\ volatile\ matter}{initial\ sample\ mass} \times 100\% \quad (2)$$

- Calculation of Ash Content

$$\%\,Kadar\ abu = \frac{mass\ of\ ash}{initial\ sample\ mass} \times 100\% \quad (3)$$

- Calculation of fixed carbon

$$\%\,fixed\ carbon = 100\% - (\%Moisture\ content + \%Volatile\ matter + \%Ash\ Content) \quad (4)$$

- Calorific Value

$$Calorific\ Value = \frac{(\Delta T \times W) - E_2}{m} \quad (5)$$

- Sulfur Content

$$\% \, Total \ Sulfur = \frac{Ar \ Sulfur}{Mr \ BaSO4} \times mass \ of \ combustion \ residue \times 100\% \quad (6)$$

Where, ΔT as Temperature change ($^0$C); calorific value is the energy produced with units Cal/g or Kcal/kg; W as Equivalent energy from standardization (2,396 Cal/$^0$C); E2 as fuse wire correction (2.3 Cal/cm = 23 Cal/10cm); m as mass of sample analyzed in the bomb calorimeter.

### 2.3. Shatter Index Test

Shatter index test was conducted to test the durability of the briquettes made against impact. The test was conducted by dropping the briquettes from a height of ± 1.8 meters above the surface. The treatment aims to review how strong the briquette is against impact caused by height and how many particles are lost or released from the briquette (Mimut, 2021). The following formula is used to measure the shatter index (Oriabure et al., 2017):

$$\% \, Shatter \ Index = \frac{(initial \ mass - final \ mass)}{initial \ mass} \times 100\% \quad (7)$$

## 3. Result and Discussion

### 3.1 Characterization of Briquette Raw Materials

The quality of raw materials can be assessed based on proximate analysis by measuring the parameters of moisture content, volatile content, ash content, and fixed carbon. In addition, measurements of calorific value and sulfur content are also used to describe the quality of briquette raw materials. The initial characteristics of the raw materials can be seen in Table 2.

**Table 2.** Raw material characteristics of briquettes

| Sample | Moisture Content (%) | Volatile Matter (%) | Ash Content (%) | Fixed Carbon (%) | Sulfur Content (%) | Calorific Value (Kcal/kg) |
|---|---|---|---|---|---|---|
| Bottom Ash | 1.50 | 20.35 | 40.40 | 37.74 | 0.55 | 2,849 |
| Fly Ash | 7.73 | 10.03 | 29.51 | 52.73 | 1.09 | 899 |
| WWTP sludge | 5.92 | 55.07 | 29.27 | 9.74 | 1.82 | 3,498 |
| Biomass | 7.22 | 58.11 | 26.75 | 7.92 | - | 2,172 |

Based on the measurement results in Table 2, the moisture content contained in all samples of raw materials is in accordance with the requirements (< 17%, SNI 4931: 2010 requirements). Low moisture content in briquette raw materials will affect the quality of the briquettes produced because it can affect the combustibility of the briquettes (Miharja, 2016). The measured volatile content illustrates the combustible material during combustion, where from the measurement results, the WWTP sludge and biomass samples have the largest combustible material (Zhu, 2014). In terms of ash content, the bottom ash sample has the highest value, indicating that the inorganic residue produced is the most so that it can potentially form deposits and scale in the combustion chamber (Prameswari, 2017). The heating value produced from the four samples varies greatly, this heating value describes the energy that can be produced by a material (Zhu, 2014). The WWTP sludge sample has the highest calorific value of 3,498 Kcal/kg. This calorific value is higher when compared to the textile industry WWTP sludge studied by Rahmaulina et al (2022) which is only 1,172 Kcal/kg. Furthermore, to determine the feasibility of the raw material samples, a comparison was made between the characteristics of the raw materials and criteria of the PerMen LHK 06/2021. The comparison results can be seen in Table 3.

**Table 3.** Comparison of raw material characteristics with PerMen LHK 06/2021

| Parameter | Quality Standard | Unit | Result | | | |
|---|---|---|---|---|---|---|
| | | | Bottom Ash | Fly Ash | WWTP Sludge | Biomass |
| Calorific Value | ≥ 2,500 Kcal/kg | Kcal/kg | 2,849 | 899* | 3,498 | 2,172* |
| Total Organic Halogen/TOX content | ≤ 2% | % | | | - | |
| Sulfur Content | ≤ 1% | % | 0.55 | 1.09* | 1.82* | 0.27 |

**: Does not meet the criteria PerMen LHK 06/2021*

Based on Table 3, the bottom ash sample met the criteria for both parameters measured, the fly ash sample still did not meet the criteria for both parameters measured, the WWTP sludge sample only met the criteria for caloric content (heating value), and the biomass sample only measured caloric content but still did not meet the criteria. Based on this comparison, as a raw material for fuel, the bottom ash sample has the best quality according to PerMen LHK 06/2021 because it meets the criteria for calorific value and sulfur content. Although the caloric content of the WWTP sludge sample has a higher value than the bottom ash sample, the sulfur content parameter does not meet the criteria. Although other samples do not meet the criteria of PerMen LHK 06/2021, they still have the potential to be used as briquette raw materials, because according to Indriyani et al (2015), the calorific value can be increased by adding other potential sources of calories from other samples as briquette raw materials.

In addition to comparing with PerMen LHK 06/2021, fuel viability can be assessed using a Tanner diagram, where the parameters reviewed are moisture content, ash content, and volatile matter. Based on the Tanner diagram, if a material falls into the grey zone, it can be burned without additional fuel (Taşpınar & Uslu, 2018). The results of the raw material sample assessment can be seen in Figure 1.

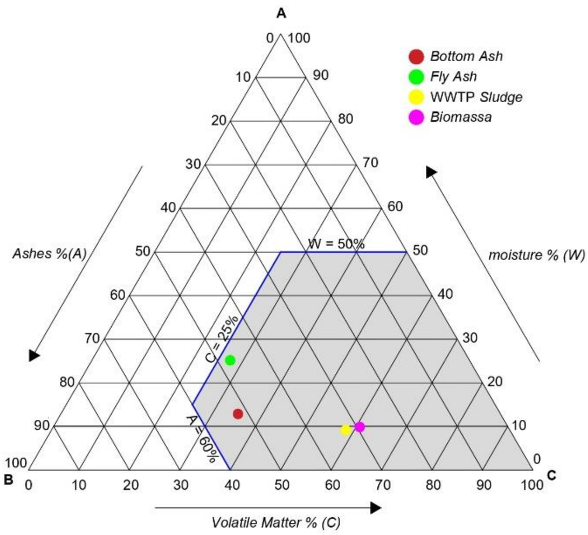



**Figure 1**. Raw material sample assessment with tanner diagram

Based on Figure 1, samples of bottom ash, fly ash, WWTP sludge, and urban waste biomass indicate that they are suitable to be used as fuel for the combustion process without additional fuel, this is because all raw material samples have met the criteria required by the Tanner diagram, namely the parameters of moisture content <50%, ash content <60%, and combustible content >25% so that the raw material samples can be used for the combustion process without the need to add additional fuel. These three parameters greatly affect the combustion process of a fuel, where the moisture content parameter if too high will slow down the combustion process because the energy produced will focus on removing the moisture content first (Miharja, 2016). Then, the volatile content parameter is needed to predict a fuel's potential flash point and combustion (Setiani et al., 2019). Meanwhile, the ash content parameter produced by the fuel needs to be known to predict the combustion residue, where the fuel should not produce a lot of residues because it can form deposits and scale on the combustion chamber components, thus disrupting the combustion process (Prameswari, 2017).

### 3.2. Characteristics of Briquette Products

After conducting an initial characterization of the raw materials (bottom ash, fly ash, WWTP sludge, and municipal waste biomass), a mixture of the four raw materials was experimented to be made into briquettes with three formulas that had certain composition variations (can be seen in Table 1) and then carried out the characterization of the briquettes made. In this study, fly ash samples were used as one of the raw materials for briquettes, which were not used in research conducted by Rahmaulina et al (2022) and Marganingrum et al (2020). The results of the characterization can be seen in Table 4.

**Table 4.** Characteristics of briquette products

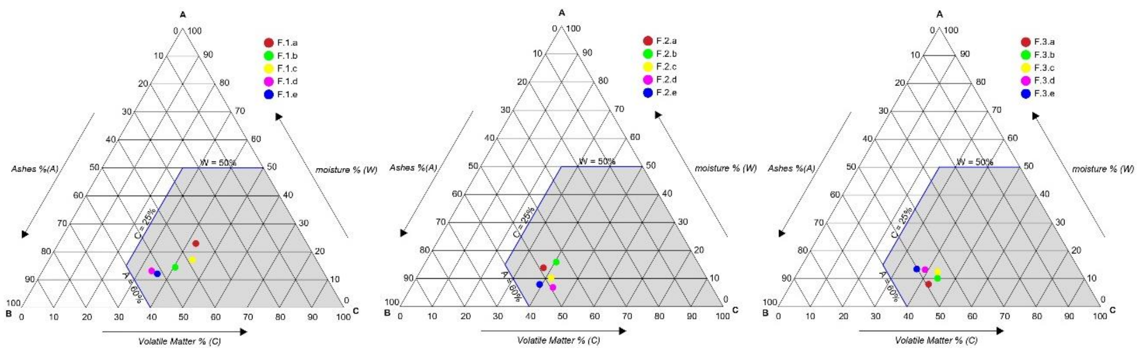
| Sample code | Moisture Content (%) | Volatile Matter (%) | Ash Content (%) | Fixed Carbon (%) | Calorific Value (Kcal/kg) | Sulfur Content (%) |
|---|---|---|---|---|---|---|
| F.1.a | 7.71 | 27.39 | 45.70 | 19.20 | 3,551 | 0.86 |
| F.1.b | 7.44 | 33.48 | 38.06 | 21.02 | 3,414 | 0.79 |
| F.1.c | 8.35 | 35.73 | 29.67 | 26.25 | 3,578 | 0.70 |
| F.1.d | 7.18 | 27.85 | 47.08 | 17.89 | 2,821 | 0.91 |
| F.1.e | 6.94 | 30.94 | 46.64 | 15.48 | 2,685 | 0.95 |
| F.2.a | 7.06 | 30.68 | 40.90 | 21.36 | 3,410 | 0.88 |
| F.2.b | 8.21 | 32.77 | 36.04 | 22.97 | 3,344 | 0.86 |
| F.2.c | 1.57 | 39.37 | 32.99 | 26.07 | 3,890 | 0.82 |
| F.2.d | 2.01 | 39.15 | 44.48 | 16.36 | 2,987 | 0.94 |
| F.2.e | 2.07 | 33.37 | 46.93 | 17.63 | 3,079 | 1.12* |
| F.3.a | 1.45 | 36.01 | 42.67 | 19.88 | 2,939 | 1.15* |
| F.3.b | 1.82 | 36.76 | 37.11 | 24.32 | 3,318 | 1.05* |
| F.3.c | 1.94 | 35.71 | 36.50 | 25.85 | 3,864 | 0.96 |
| F.3.d | 7.04 | 32.68 | 41.53 | 16.76 | 3,103 | 1.15* |
| F.3.e | 7.66 | 30.43 | 44.95 | 16.96 | 3,055 | 1.29* |

**: Does not meet the criteria PerMen LHK 06/2021*

Table 4 shows a comparison of the characteristics of the briquettes made by varying the composition of the raw materials. Differences in the characteristics produced can be caused by variations in the composition of the raw materials used. From the measurement of proximate analysis, the water content contained in all briquettes has a low value because it is < 17% (SNI 4931: 2010), this low water content will make it easier for briquettes to burn in the combustion process (Miharja, 2016). The volatile matter of the briquettes made has a value that is relatively not much different, which means that all briquettes have flammable material that is relatively not much different, this volatile content is important to know because it can predict the flash point and burnability of a fuel (Setiani et al., 2019). The ash content parameter of the briquettes produced a fairly high value (<20%, SNI 4931:2010 criteria). High ash content in briquettes can potentially form deposits and scale in the combustion chamber (boiler) (Prameswari, 2017). Of the three briquette formulas, the ones with the highest fixed carbon in each formula are sample codes F.1.c, F.2.c, and F.3.c.

The quality of coal can be seen from the relationship between the parameters of carbon content and heating value, where the greater the level of fixed carbon, the greater the energy produced. However, this still takes into account the configuration of other parameters (Miharja, 2016). In terms of calorific value, the briquette products that produced the highest calorific value were briquette products with sample codes F.1.c (3,578 Kcal/kg), F.2.c (3,890 Kcal/kg), and F.3.c (3,864 Kcal/kg). The high calorific value in a sample can produce a reduction fire, where the fire is blue with a higher temperature and produces lower smoke/gas compared to samples that have low calorific value, but this still needs to pay attention to the configuration of other parameters (Miharja, 2016). The calorific value parameter is the most commonly used quality measure (Zhu, 2014). The three briquettes have the same composition of coal waste, namely 50% bottom ash and 10% fly ash. Then the quality of briquettes is compared with PerMen LHK No. 06 of 2021 which can be seen in Table 5.

In PerMen LHK 06/2021, the parameters regulated by the criteria are calorie content (≥2500 Kcal/kg), sulfur content (≤ 1%), and total organic halogen - TOX (≤ 2%). The comparison of the calorie content criteria in PerMen LHK 06/2021 with the calorie content produced by the briquettes, it shows that all variations of briquettes made have met the required criteria of ≥2500 Kcal/kg. As for the sulfur content parameter of all briquettes made, only 5 briquettes did not meet the criteria of PerMen LHK 06/2021 because the value exceeded 1% (can be seen in Table 4). The sulfur content of the briquettes can be caused by the raw materials, based on the measurements (in Table 4). The sulfur content increases with the percentage of fly ash and the percentage of WWTP sludge used as raw materials for each briquette. This may be due to the high sulfur content of fly ash and WWTP sludge (> 1%). If the sulfur content parameter does not meet the criteria, $SO_2$ can be emitted into the air from the combustion of the briquettes and cause corrosion and slagging of the combustion equipment (Speight, 2005). All briquettes made are expected to have TOX content that meets the criteria of PerMen LHK 06/2021 so that they do not have the potential to cause negative impacts on the environment and humans. This TOX parameter is indicated by the chlorine content contained in the raw materials and briquette products. Based on research conducted by Marganingrum et al (2021), samples of WWTP sludge, bottom ash, and biomass have chlorine contents of 0.19%; 0.05%; and 0.43. These results have met the criteria of PerMen LHK 06/2021, and indicate that the samples are safe for the environment.




(a) (b) (c)

**Figure 2.** Assessment of briquette samples using tanner diagram: (a) Formula 1, (b) Formula 2, and (c) Formula 3

Figure 2 shows the results of inputting the parameters of moisture content, ash content, and combustible content (volatile matter) of the briquette samples from formula 1, formula 2, and formula 3 into the Tanner diagram. Based on the Tanner diagram, all briquette formulas with each variation fall into the ash-colored zone in the Tanner diagram. In other words, the briquette formulations used are suitable be used as fuel for the combustion process without additional fuel. These three parameters greatly affect the combustion process of a fuel, where the moisture content parameter if too high will slow down the combustion process because the energy produced will focus on removing the moisture content first (Miharja, 2016). Then, the volatile content parameter is needed to predict a fuel's potential flash point and combustion (Setiani et al., 2019). Meanwhile, the ash content parameter produced by the fuel needs to be known to predict the combustion residue, where the fuel should not produce a lot of residues because it can form deposits and scale on the combustion chamber components, thus disrupting the combustion process (Prameswari, 2017). Briquettes made in this study have been better than briquettes in research conducted by Rahmaulina et al (2022) because briquettes made from bottom ash and WWTP sludge raw materials have not met the provisions of the Tanner diagram so these briquettes cannot be used as fuel for the combustion process without additional fuel. This can be caused by three parameters that are the criteria of the Tanner diagram, which are moisture content, volatile content, and ash content.

### 3.3. Shatter Index Test

**Table 5.** Shatter index test results of briquettes

| Sample Code | Average Shatter Index (%) |
|---|---|
| F.1.a | 17.12 |
| F.1.b | 53.63 |
| F.1.c | 37.29 |
| F.1.d | 46.96 |
| F.1.e | 13.94 |
| F.2.a | 61.66 |
| F.2.b | 23.36 |
| F.2.c | 52.90 |
| F.2.d | 45.22 |
| F.2.e | 13.77 |
| F.3.a | 68.68 |
| F.3.b | 33.87 |
| F.3.c | 33.20 |
| F.3.d | 45.71 |
| F.3.e | 5.78 |

Based on the shatter index measurement results (Table 5), the briquettes that have the smallest shatter index (% loss) of each formula are briquettes F.1.e, F.2.e, and F.3.e. This indicates that these three briquettes have better strength compared to the other briquette formulations. This indicates that these three briquettes have better strength when compared to other briquette formulations. The three briquettes have the same percentage of FABA which is 10% bottom ash and 50% fly ash. However, this shatter index value does not meet the required criteria, because the briquettes produced must have a resilience value of 95% or the loss of briquettes due to impact cannot be more than 5% (Safitri, 2020). This shatter index measurement data is useful when handling briquettes to the boiler combustion chamber, so that the briquettes used later are not destroyed when entered into the combustion chamber.

### 3.4. Optimum Briquettes Quality

In this study, the quality of briquettes was determined based on proximate analysis, calorific value analysis, and sulfur content analysis. Of all the briquette variations made, the briquettes that have optimum quality according to the criteria in the Minister of Environment and Forestry Regulation No. 06 of 2021 (PerMen LHK 06/2021) are F.1.c (3,578 Kcal/kg), F.2.c (3,890 Kcal/kg), and F.3.c (3,864 Kcal/kg). And all three samples have sulfur content of < 1%. In addition, these three briquettes have met the requirements of the Tanner diagram (into the ash-colored zone) based on proximate analysis. However, the three briquettes still have a shatter index value that does not meet the criteria of <5% (Safitri, 2020). The three formulas have a composition of 50% bottom ash and 10% fly ash.

## 4. Conclusions

Based on the research conducted, the samples of bottom ash, fly ash, WWTP sludge, and urban waste biomass have the potential to become solid fuel raw materials in the form of briquettes. This is indicated by the results of proximate analysis and the calorific value of all briquette samples made producing good quality. The quality of the briquettes was determined by comparing the calorific value of the briquettes with the criteria of PerMen LHK No. 06 of 2021, where all briquettes met the required calorific value criteria. In addition, the quality assessment of the briquettes was carried out using a Tanner diagram. All briquettes met the requirements of the Tanner diagram because they entered the grey zone.

From all the briquettes made, there are three briquettes from each formula that have the best quality, namely briquettes with sample codes F.1.c, F.2.c, and F.3.c with a calorific value obtained 3,578 Kcal/kg; 3,890 Kcal/kg; and 3,864 Kcal/kg. Furthermore, the three briquettes have a sulfur content of < 1%. The three formulas have the same composition of coal waste raw materials, namely 50% bottom ash and 10% fly ash. The results show that the briquette products can be used for co-firing fuel.

The use of bottom ash can improve the quality of briquettes based on the parameters of ash content, fixed carbon, and sulfur content. This is because an increase in the use of bottom ash from briquettes results in low ash content and sulfur content, as well as high fixed carbon. While the use of fly ash can reduce the quality of briquettes, because the composition of fly ash is inversely proportional to the composition of bottom ash, so it is necessary to further consider the use of fly ash as one of the raw materials for briquettes. In addition, samples of WWTP sludge and biomass from fermented municipal solid waste were used to increase the volatile content and will then accelerate the combustion process of the briquettes.

## Acknowledgement

The author would like to thank the National Research and Innovation Agency (BRIN) and the Bandung National Institute of Technology (ITENAS) for the assistance provided for the research that the author carried out, as well as thanks to all staff who contributed to the research process at the BRIN Laboratory and supervisors who have taken the time, provided direction, guidance, knowledge, and input for the author in completing this research.

## References

Afriyanti, Y., Sasana, H., and Jalunggono, G. 2020. Analisis Faktor-Faktor yang Mempengaruhi Konsumsi Energi Terbarukan di Indonesia. Directory Journal of Economic, 2 (3), 865-884.

American Society for Testing and Materials (ASTM) D 5142 Standard Test Methods for Proximate Analysis of the Analysis Sample of Coal and Coke by Instrumental Procedures.

American Society for Testing and Materials (ASTM) D 5865 Standard Test Methods for Gross Calorific Value of Coal and Coke.

Dikjen Pengelolaan B3. 2015. Dioxin Furan. November 17, 2022. https:// sib3pop.menLHK.go.id/ index.php/dirtydozen/view?slug=dioxin-furan.

Indriyani, Zaman, B., and Syarifrudin. 2015. Pemanfaatan Bottom Ash Batubara Menjadi Produk Briket dengan Penambahan Arang Daun Jati. Jurnal Teknik Lingkungan.

Marganingrum, D., Estiaty, L. M., Irawan, C., and Hidawati. 2020. The Biomass Coal Fermented (BCF) Briquette as an Alternatif Fuel. MSCEIS, 2019.

Marganingrum, D., Hidawati, and Djaja, S. D. S. 2021. A Preliminary Study of Fuel Mixture of Industrial Sludge, Bottom Ash, and Municipal Solid Waste for Co-Firing in Coal Boilers

Marganingrum, D., Irawan, C., Mursito, A. T., Estiaty, L. M., Listyowati, N. L., Arifin, D. N., and Hidawati. 2021. The Economics Assessment on The Utilizing of Bottom Ash ash The Bio Coal Fuel. Jurnal Eknomi dan Pembangunan, 29 (1).

Miharja, M. H. J. 2016. Analisis Proksimat Potensi Briket Bioarang sebagai Energi Alternatif di Desa Kusu, Maluku Utara. Jurnal Techno, 1, 15-21.

Mimut, A. R. 2020. Pengaruh Variasi Jumlah Campuran Bahan Perekat Terhadap Karakteristik Briket Arang Tongkol Jagung. Skripsi. Mataram: UMM.

Oriabure, E. D., Terzungwue, T. E., and Emoh, O. F. 2017. Desity, Shatter Index and Heating Value of Briquettes Produced form the Leaves of Terminalia Mentalis and Sawdust of Daniela Oliveri. International Journal of Pure Agricultural Advances. 1 (1), 34-44.

Prameswari, W. A. 2017. Analisa Pembentukan Slagging dan Fouling Pembakaran Batubara pada Boiler B 0201B Pabrik 3 Unit UBB di PT. Petrokimia Gresik. Surabaya: ITS.

Rahmaulina, D., Hartati, E., and Marganingrum, D. 2022. Studi Pendahuluan Pemanfaatan Sludge IPAl Industri Tekstil Sebagaia Bahan Baku Briket. Jurnal Teknologi Lingkungan, 23 (1), 035-043.

Republik Indonesia. 2020. Peraturan Menteri Lingkungan Hidup dan Kehutanan No. 18 Tahun 2020 tentang Pemanfaatan Limbah Bahan Berbahaya dan Beracun.

Republik Indonesia. 2021. Peraturan Menteri Lingkungan Hidup dan Kehutanan No. 06 Tahun 2020 tentang Tata Cara dan Persyaratan Pengelolaan Limbah Bahan Berbahaya dan Beracun.

Safitri, E. D. 2020. Pembuatan Briket dari Campuran Cangkang Biji Karet (Hevea brasiliensis) dan Tandan Kosong Kelapa. Lampung: UIN.

Setiani, V., Setiawan, A., Rohmadhani, M., and Maulidya, R. D. 2019. Analisis Proximate Briket Tempurung Kelapa dan Ampas Tebu. Jurnal Presipitasi. 16 (2), 91-96.

Speight, J.G. 2005. Handbook of Coal Analysis. Vol. 166, John Wiley & Sons, Inc.

Standar Nasional Indonesia Nomor 4931 Tahun 2010 Tentang Briket Batubara.

Taşpınar, F. and Uslu, M. A. 2018. Evaluation of Combustibility and Energy Potensial of Municipal Solid Waste: The Case of Esenler Municipality. International Journal of Energy Applications and Technologies, 5(1), 1-8.

Yustanti, E., Muharman, A., and Mursito, A. T. 2022. Karbonisasi Redwood Indonesia dengan Rotary Kiln untuk Pembuatan Bio-Coke dengan Binder Wood Tar Hasil Karbonisasi.

Zhu, Q. 2014. Coal Sampling and Analysis Standards. London: IEA Clean Coal Centre.