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Review article

Comparison of various methods of processing plastic waste into economical briquettes

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Abstract
The industrial revolution, which has an impact on the emergence of environmental issues, began with the increasing demand for energy in global transportation, industry, and home activities. An idea that has good potential in reducing reliance on traditional energy sources is the innovation of processing waste into alternative energy sources. Processing plastic waste into plastic briquettes, an alternative fuel, including tertiary recycling. Several different techniques and adhesive materials can be used to turn plastic trash into alternative fuels. Only one type is produced via carbonization. Plastic briquettes (PP) can produce a higher heating value of 9982.779±240.017 cal/gram and 3.90% ash content. It creates a high ash content but also has a 7024.56 calorie per gram and a 0.27% ash content from plastic briquettes (PET), which is a result of the impurities still present. Meanwhile, for the type of adhesive with the same composition as briquettes with starch adhesive, the heat value was 6328 kcal/kg, arpus 6366 kcal/kg. Despite having a higher calorific value, the arpus adhesive typically produces briquettes that emit black smoke due to the composition of the arpus which is made from rubber tree sap.

INTRODUCTION

The increasing need for energy in transportation, industry, and domestic activities around the world is the starting point of the industrial revolution which has an impact on the emergence of environmental problems. Climate change, economic growth, and changes in consumption and production patterns are factors that increase the accumulation of plastic waste in the world. Around 5 million tons of waste in the 1950s increased to 100 million tons/year. So it can be seen that with the increasing demand for plastic in the world, the accumulation of plastic waste will also increase (Bhoumick, 2016). The limited availability of primary energy sources in Indonesia encourages the government to look for alternative energy sources as an effort to fulfill very high energy consumption and reduce the use of fossil fuels in industrial and household activities. Plastics are often resistant to corrosion, have a low specific gravity, are ductile and strong, and are soft at cold temperatures, making them an ideal replacement for solid fuels like briquettes, which have high calorific value, rate of burning, and duration of combustion (Suryaningsih, 2010).

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However, in making briquettes from plastic waste, it is more difficult to use liquid fuels such as diesel and gasoline using the pyrolysis method. Therefore, it is necessary to do engineering so that it can be made into solid fuel. One of the uses of plastic waste that has been carried out by several researchers is plastic waste into briquette making materials, the results obtained are that the addition of plastic to briquettes made from organic waste or agricultural waste can increase the calorific value. The application of plastic into briquettes aims to fulfill energy that is starting to become scarce (Ningsih, 2020). Therefore, the objective of this review is to provide information, ideas as well as evaluation activities of previous research in order to give suggestions for further research on processing plastic waste into briquettes.

RESULTS AND DISCUSSION

Plastic waste treatment methods

Plastic waste processing with the 3R concept generally aims to reduce the quantity or improve the characteristics of the waste, which will be processed further. Based on research conducted by Lestari (2020), briefly describes the application form of the 3R concept, which is as follows:

1. Reducing the use of plastic, for example replacing the use of plastic shopping bags with cloth shopping bags or other environmentally friendly materials so as not to increase the volume of existing waste.
2. Reuse, Reusing plastic items that are considered useless, such as plant pots made of plastic cups filled with mineral water, etc.
3. Recycle, Recycling plastic waste, for example recycling using technology, plastic waste can be processed into alternative energy in the form of briquettes from plastic waste.

Polyethylene Terephthalate (PET, PETE)

Polyethylene Terephthalate (PET) is a polymer that has a molecular weight ranging from 30,000–80,000 gmol-1. This type is a semi-crystalline polymer which is chemically stable thermally (Alshehrei, 2017). PET plastic is suitable to be applied to goods that have the criteria of large capacity, light weight, and pressure resistance (Sharuddin, 2016). In addition, PET plastic is transparent, smooth, and relatively thin (Alabi, 2019). PET is usually referred to as a polyester which has a functional ester group that can be broken down using several reagents including alcohol (alcoholysis), glycols (glycolysis), water (hydrolysis), amines (aminolysis), and acids (acidolysis). Thus, the PET chemical recycling process is divided into alcoholism, hydrolysis, glycolysis, and others (Achilias, 2012).

Polypropylene (PP)

Polypropylene is a saturated polymer which is semi-transparent and strong. Compared to polyethylene, polypropylene is heavier and less hazardous. The use of polypropylene plastic is usually used as food and beverage containers that are safe to use (Alabi et al., 2019). The presence of linear hydrocarbon chains in PP plastic makes this plastic has good chemical and heat resistance. The large number of uses of PP plastic can increase the accumulation of PP plastic waste, so it is necessary to recycle PP plastic waste. One of the methods used in processing PP plastic waste is the pyrolysis method which can convert waste into alternative energy sources (Sharuddin, 2016).

Briquette

One of the alternative sources of fuel that is widely known is briquettes. Briquettes are the result of converting coal, organic waste, factory waste and from urban waste into fuel that is more effective, efficient and easy to use (Sawir, 2016). The briquettes produced are then analyzed for the quality of the briquettes using the proximate analysis (Ningsih, 2020).

Table 1. The Standard of Various International Briquettes (Anggoro, 2017)

No	Parameter	Japan	England	USA	SNI
1	Moisture content (%)	06−08	3,6	6,2	8
2	Volatile matter content (%)	15−30	16,4	19−28	15
3	Ash content (%)	3−6	5,9	8,3	8
4	Fixed carbon content (%)	60−80	75,3	60	77
5	Density (g/cm^3)	1,0−1,2	0,46	1	-
6	Compressive strength (g/cm^2)	60−65	12,7	62	-
7	Calorific value	6000−7000	7289	6230	5000

Quality standard of briquette

The quality of charcoal briquettes is generally determined based on their physical and chemical properties such as moisture content, volatile matter content, ash content, fixed carbon content, density, compressive strength, and calorific value. Meanwhile, the standard quality for Indonesian charcoal briquettes refer to the National Standard Indonesia (SNI) and also refers to the nature of charcoal briquettes made in Japan, UK and USA (Table 1).

Type of adhesive used in making briquettes

According to Ningsih (2016), there are some of the types of adhesives commonly used for charcoal briquettes, namely:

1. Adhesive aci (starch)
   A specific ratio of tapioca flour and water can be used to create aci as an adhesive, which is then heated until a paste forms.
2. Adhesive clay
   Clay adhesives can be used as adhesives for carbon-based materials. The process was done by smoothing out the clay with a sifter, then adding water until the resulting material is sticky.
3. Rubber gum adhesive
   Rubber gum adhesive has a stronger adhesive power than other types of adhesives. Charcoal briquettes with this adhesive produce thick black smoke and have an unpleasant odor when burned, so the use of this adhesive is avoided as much as possible.
4. Pine sap adhesive
   Pine sap adhesive (arpus) has almost the same characteristics as rubber gum adhesive, but has the advantage that the briquette impact force is strong enough even if the briquette is dropped from a high place or thrown hard.
5. Synthetic adhesive
   Synthetic adhesive is a special adhesive material produced by wood processing factories or industries. This type of adhesive has a very strong adhesion, but is not economical when used in the manufacture of briquettes.

Urgency briquette in Indonesia

a. Charcoal briquettes are an alternative fuel that is often used for cooking, especially for grilling foodstuffs such as in Europe, in Middle Eastern countries it is used for smoking shisha pipes, while in Asia, such as in South Korea and Japan, charcoal briquettes are used for cooking in restaurants, because Indonesian charcoal briquettes are safer, more environmentally friendly, and able to provide more heat without emitting smoke. Additionally, it has to do with the delicate subject of global warming. (Kementerian Luar Negeri Republik Indonesia, 2018).
b. The production of briquettes with a mixture of organic and inorganic waste measuring 10 mm is used for stove fuel needs, which must use a special stove. The briquettes have a calorific value of about 3400 kcal/kg equivalent to lignite. Meanwhile, for co-firing needs at the steam power plant, briquettes with a diameter of 12 mm are made, which will be used in the gasifier machine to produce gas (Mongabay, 2020).
c. Plastic waste briquettes made as an alternative fuel to replace coal will be used in the cement manufacturing process. This fuel is used to burn raw mix products to make clinker, which is the initial stage in cement manufacturing (Sawir, 2016).

Activated carbon

Activated carbon is composed of amorphous particles resulting in a complex arrangement of irregular shapes and interconnected with pores or surface area between the particles, both surface sizes of 300 - 2000 m2 /g or those with sizes of more than 2000 m2 /g. The need for activated carbon is increasing due to its applications, such as for industries and various human aids. In industrial area, activated carbon can be used for drug industry, food, beverages, water treatment (water purification) and others. Nearly 70% of activated carbon products are used for refining in the coconut oil, pharmaceutical and chemical sectors (Saputro, 2020).

Processing of briquette

1. Simple Method
   This method uses a combustion chamber in the form of a hole in the ground, a cooking kitchen, or a cooking drum. This type of burning requires a lot of time; a hole in the earth need 6-7 days to burn. (Palungkun, 2001).
2. Pyrolysis process
   The pyrolysis process is a process that decomposes a material by using high temperatures in the absence of air during the process or by using limited air. There are 3 types od pyrolysis products, such as solid product (charcoal), gas product (gas fuel) in the form of carbon dioxide (CO_2), methane (CH_4) and some gases that have small content, and liquid product (bio-oil). In general, the temperature used in the pyrolysis process is above 300°C for 4-7 hours. To minimize waste, the pyrolysis temperature is optimally attained. (Rhiduan, 2016).

Table 2. Comparison of various methods processing plastic type into briquette

Plastic type	Research result	Source
Plastic bags (PP) and plastic mineral water bottles (PET)	The variables used include the raw materials for manufacture, the temperature and time used for carbonization. The heat of burning of plastic bag waste briquettes (PP) is 10,112 cal/gram, with 3.9% ash content and 94.74% volatile content. The heat of burning mineral water glass plastic waste briquettes (PET) is 10,844 cal/gram, with an ash content of 0.27%, water content of 0.42% and volatile content of 99.27%.	Sawir, 2016
Plastic bags (PP)	The variables used include the effect of adding starch composition as an adhesive and carbonization time. Water content ranges from 0.76% to 0.88%, ash ranges from 4.2% to 7.1%, volatile ranges from 0.24% to 0.10%, and fixed carbon ranges from 94.76% to 91.94%. According to SNI criteria, briquettes made in 30 minutes with 20% starch added are of the highest grade.	Yusuf, 2021
Polypropylene (PP), Polystyrene (PS), Mixed Plastics	The variables used mixed plastics waste and lignocellulose garbage. The data show that there is 12.79% water content, 0.64% ash content, 85.14% VS content, 1.56% FC content, 0.13 g/cm3 bulk density, 8801.04 Cal/gram calorific value, and a flash point of 131.8%.	Trihadiningrum, 2007
Thermoplastics such as PC, Nylon, PET, ABS, SAN, PE, PP, PS, Polyacetal (POM), HDPE	A variety of plastics were utilized as the study's fixed variables with a particle size of 40 mesh and weighing 70 kg. The carbonization temperature, carbonization time, and adhesive concentration were the independent variables employed in this investigation. The optimum results on plastic charcoal briquettes were obtained at a carbonization temperature of 600˚C for 45 minutes with an adhesive concentration of 5% with a value of ash content (1.26%), water content (0.0098%), volatile matter (1.37%), fixed carbon (97.43%) and calorific value (7,399 kcal/kg).	Malo, 2018
Plastic LDPE (Low Density Polyethylene)	The variables used were the carbonization temperature and the composition of briquettes from kapok fruit peel and LDPE plastic. In this study, bio briquettes with optimal quality were obtained at a carbonization temperature of 500˚C with a composition of 85% kapok fruit skin (KBK) and 15% LDPE plastic where the calorific value was 6985.35 cal/g, solid carbon content was 51.12%, high carbon content was 51.12%. 4.65% moist water, 4.23% ash content and 39% volatile matter content.	Faizal, 2018
Plastic PET	The variables used are the thickness of the PET plastic, the composition of the PET plastic and dry leaves and rice husks. The best briquettes have 51.55 kg/cm2 for compressive strength, 5123 cal/g for calorific value, 12.869% ash content, 3.049% moisture content, 31.823% volatile content	Hariyanto, 2018
LDPE plastic, PP plastic, and PET plastic	The study was conducted to compare LDPE, PP and PET plastic waste in an extruder heated at a temperature of 200^{o}C. In the test results, the water content is 8-9.35% and the calorific value is at least 5000 calories/gram and has met the SNI standard.	Naryono, 2019
HDPE (High Density Polyethylene) Plastic	Comparison of the mixture of HDPE plastic and Bottom ash. The best briquettes are found in the bottom ash: HDPE plastic 4:1 ratio with a calorific value of 5352.6 cal/g, the lowest ash content is 13.58% and water content is 15.56 %.	Mirwan, 2016
Bottle caps and Snack packaging (PP plastic)	In this study, 2 types of plastic were used, namely bottle caps (Polypropylene) with a temperature of 450˚C and snack food packaging (HPDE) with a temperature of 280˚C. Carbonization time is 60 minutes. The independent variable is the combination of composition and adhesive. Based on the results of proximate analysis, with the composition of the briquette mixture (50:50) the water content was 1.5%; ash content of 7.1%; volatile matter content of 10.9%; fixed carbon of 80.5%; and the calorific value of 8565.9 cal/gram.	Ningsih, 2020

3. Carbonization process

The carbonization process is a process in which materials such as stems, leaves, coal, sawdust, coconut shells, etc., are heated in a room without contact with air during the combustion process to form charcoal. The carbonization process is one of the important stages in the manufacture of biochar briquettes. In general, this process is carried out at a temperature of 500-800℃. The content of volatile substances will be lost so that the initial pore structure will be formed (Widowati, 2003). According to Hasani (1996), the definition of the carbonization process is the incomplete combustion of organic matter using very limited oxygen, which produces charcoal and causes the decomposition of organic compounds that make up the structure of the material to form hydrocarbons, water vapor, acetic acid vapors and methanol.

4. Gasification process

Gasification is one of the thermochemical processes that can be used in the process of converting waste into energy. Gasification has several general steps in the process, namely the drying process, the pyrolysis process, the reduction process, and the partial combustion process. In addition, gasification also uses gasification media in the form of air, oxygen or water vapor. The gas produced by the gasification process is commonly referred to as producer gas or syngas (synthetic gas). Syngas produced by the gasification process can be used directly by burning, can be used as fuel for internal combustion engines, or used as raw material for further chemical processes (Yuwono, 2016).

Based on Trihadingrum's research (2007) briquettes from mixed plastic waste and lignocellulosic were found in M20T40 briquettes with the following quality characteristics such as water content 12,79%, ash content 0,64%, VS content 85,14%, FC content 1,56%, bulk density 0.13 g/cm3, calorific value 8801.04 cal/gram and flash point 131.8 °C. This result is in accordance with the standard of Minister of Energy and Mineral Resources No. 47 of 2006. According to Sawir's (2016) research, briquettes from plastic bags (PP) obtained a calorific value of 10,112 cal/gram, with an ash content of 3.90%, water content of 0.36% and volatile content of 94.74%. Then, briquettes from mineral water plastic cups (PET) obtained calorific value of 10,844 cal/gram, with ash content of 0.27%, water content of 0.42% and volatile content of 99.27% and both are in accordance with the standard of SNI 19-2454- 1991. The bioplastic briquettes created in this study demonstrated that the calorific value, moisture content, and ash content acquired had met the quality standards of SNI, in accordance with Rifdah's (2013) research on the influence of the percentage composition of PET and sticky plastics. The calorific value produced under optimal conditions is 7024.56 cal/gr, 3.74% water content and 5.0% ash content. Optimal conditions plastic percent at 24% and 20% adhesive percent. Ningsih and Udyani (2020) reported that charcoal briquettes from plastic bottle waste is in accordance with SNI were under conditions of 40 mesh charcoal particle size, with a water content of 0.5±0.05%, an ash content of 2±0 .25%, volatile content of 15±0.51%, bound carbon content of 82.5±0.32%, and calorific value of 9982.779±240.017 cal/gram.

Afterward, Yusuf *et al*. (2019) demonstrated that when starch was used as an adhesive in PP plastic briquettes, the resulting materials had moisture contents between 0.76% and 0.88%, ash contents between 4.2% and 7.1%, volatile matter between 0.24% and 0.10%, and fixed carbon contents between 94.76% and 91.94%. The best quality of briquettes according to SNI standards is found in 30 minute briquettes with the addition of 20% starch. The influence of adhesive type on briquette burning time, tapioca, palm sago, and arpus in oil palm shell briquettes was reported by Aziz et al. in 2019. It showed that the calorific value of tapioca adhesive was 6328 kcal/kg, sugar palm sago 6330 kcal/kg and arpus 6366 kcal/kg, the moisture content was 6.0% tapioca adhesive, 6.7% palm sago and 5.5% arpus, 7.70% ash content of tapioca adhesive, 6.74% sugar palm sago and 7.11% arpus. Thus, the results of the study indicated that the type of adhesive used had an impact on quality standards of the briquettes.

CONCLUSION

Plastic briquettes can be produced using a variety of processes, raw materials, and adhesives. Heating temperatures for the production of briquettes utilizing the carbonization process to make charcoal from biomass products typically vary from 400 to 600 °C, while heating temperatures for pyrolysis are typically higher than 300 °C. In the manufacture of briquettes with the pyrolysis method, it has advantages such as the temperature and initial raw materials that are almost the same as the carbonization method, which results in briquettes with a higher heating value, more products produced, and produces two different charcoals (from pitot tubes and fuel). However, carbonization only produces one type briquettes. Plastic briquettes

(PP) can produce a higher heating value of 9982.779±240.017 cal/gram and 3.90% ash content. From plastic briquettes (PET) create 7024.56 cal/gram but also produces a high ash content, this is because there are still impurities in it. Meanwhile, for the type of adhesive with the same composition as briquettes with starch adhesive, the heat value was 6328 kcal/kg, arpus 6366 kcal/kg. Despite having a higher calorific value, arpus adhesive typically produces briquettes that emit black smoke since it is manufactured from the sap of rubber trees.

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