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CALORIFIC VALUE OF PALM KERNEL SHELL CHARCOAL (PKSC) BRIQUETTE AS SOLID FUEL

Hendri Nurdin[1*], Waskito[2], Fadhilah[3], Toto Sugiarto[4], Andre Kurniawan[5], Yolli Fernanda[6], Rudy Anarta[7], Fathi Aulia DZ[8]
Department of Mechanical Engineering, Universitas Negeri Padang, Padang, Indonesia[1256]
Department of Mining Engineering, Universitas Negeri Padang, Padang, Indonesia[378]
Department of Automotive Engineering, Universitas Negeri Padang, Padang, Indonesia[4]
hens2tm@ft.unp.ac.id[1]

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Corresponding Author

ABSTRACT
The need and utilization of energy in society exceed available production. This condition requires acceleration and efforts to find solutions through the diversification of palm shell biomass into solid fuel briquettes. Palm shells have the potential as biomass and renewable energy sources that are selected based on strategic, technical, and environmental considerations. Its utilization so far has only been burned directly which causes air pollution or used as road paving in oil palm plantations. The environmental impact is the accumulation of solid waste, and global warming in the Crude Palm Oil processing industry. The research objective was to obtain the calorific value of palm kernel shell briquettes with carbonization process. The experimental research method carried out by innovating palm kernel shell briquette raw materials at various percentage variances (90%: 10%, 85%: 15%, 80%: 20%, 75%: 25%) using tapioca adhesive. The technical parameters of briquettes making are molding pressure of 10 MPa, particle grains of 60 mesh, carbonization temperature of 400^{o}C; 450^{o}C; 500^{o}C with a holding time of 1 hour. From this study, the calorific value of palm kernel shell charcoal (PKSC) briquettes at a concentration of 85%;15% at a temperature of 400^{o}C was 25.86 MJ/kg with tapioca adhesives as the highest calorific value parameters. The technology used to make palm kernel shell charcoal briquettes is a potential development that can be recommended as a precursor to solid fuels. The impact of developing PKSC biomass energy briquettes is an innovation in utilizing waste to create solid fuels. The implications of this research can be applied by home industries or households. This research is a contribution to solutions in overcoming energy needs and deficiencies as a form of sustainable energy.
Keywords: *Briquettes, Palm Kernel Shell Charcoal, Calorific Value, Carbonization, Solid Fuel.*

1. Introduction

The demand for energy is increasing due to the ever-increasing usage. Dependence and limitations on existing energy will lead to price instability, so that the country has difficulty meeting expensive energy needs. In this condition, a solution is needed to solve it by finding an alternative energy source. Accelerating the provision of alternative energy options and adoption are the steps taken forward. The great potential in Indonesia is biomass, which is a renewable energy as green energy. The National Energy Policy formulates an increase in the utilization of biomass renewable energy into new solid fuels. More applicable development is needed to obtain solid fuel as alternative energy. Biomass briquetting, a densification technology used in increasing the potential use of biomass energy (Carter et al., 2018). Briquettes are solid fuels that are processed by appropriate methods into a useful product form. Briquetting is an appropriate method to convert biomass into a specific form after the compaction process so that it can be more easily utilized. Biomass has a relatively low energy density due to its high volatile matter content and moisture content, reducing its thermal efficiency (Jeong et al., 2020). Some of the requirements of a good briquette are that it has a flat texture and no black marks, is easy to ignite and does not emit a lot of smoke, non-toxic gas emissions, watertight and not moldy, showing high combustion rate. In briquetting, there are three ways of briquetting technology which are affected by molding pressure, heating, binders. The briquetting process was developed by low compaction using clay, bentonite and yucca starch binders and high compaction without binders (Tamrin, 2016). The bonding ability of compacted materials is greatly influenced by organic or inorganic binders (Obi et al., 2022). The use and selection of binders needs to be considered, because it can affect the combustion heating value.

In the search for biomass feedstocks that have potential as innovative products for energy needs. The selection of palm kernel shells as a biomass energy source is based on strategic, technical, and environmental considerations. Recent research has explored the potential of palm oil waste as an alternative fuel source. Researchers have investigated the production of briquettes from palm shells and fibers, finding that these materials can produce briquettes with promising characteristics. Environmentally friendly disposal of palm kernel shells is still rarely done in Indonesia (Nabila et al., 2023). Palm kernel shells are usually only burned directly or only used as pavement in plantations, so their utilization into charcoal briquettes actually increases their economic value. By utilizing existing waste, simple technology, and a more controlled environmental impact, palm kernel shell briquettes are a logical choice in the renewable energy transition (Abogunrin-Olafisoye et al., 2024). Palm kernel shell biomass briquettes as an energy mix that converts biomass into a highly efficient solid fuel (Ukpaka et al., 2019). Solid fuel as a biomass energy development can be realized by utilizing palm kernel shells. Palm kernel shell is the innermost part of the oil palm fruit and has a hard structure. After processing the oil palm fruit, the shell cannot be processed into oil and only becomes the solid waste factory. Palm kernel shell as a biomass product as a source of biofuel, has a high content so that it can produce a large maximum heat energy (Ikumapayi & Akinlabi, 2018). It is very suitable for further processing to facilitate efficient use as a briquetted solid fuel. The huge and valuable potential of palm kernel shells to augment energy security through renewable technologies (Okoroigwe & Saffron, 2012). Tsai's research (Tsai, 2019) found the utilization of palm kernel shells as an energy source in Taiwan resulted in significant benefits both from an environmental and economic perspective. Palm kernel shell briquettes proved to be an environmentally friendly and cheaper solid fuel to produce with a heating value of 18.72 MJ/kg (Osei Bonsu et al., 2020). Research on the potential of tibarau sugarcane as a fuel after being extracted and then made into briquettes. Hybrid briquettes of bagasse and durian peel mixture have a calorific value of 14.92 MJ/kg at a mixture of 80%:20% and a density of 0.619 g/cm^3 (Nurdin H et al., 2017). The tibarau sugarcane plant has the ability to produce low levels of bioethanol has the heat energy or calorific value after the distillation and fermentation process. Potential of tibarau sugarcane can be recommended for biofuel development (Hasanuddin et al., 2015). Tibarau sugarcane briquettes with tapioca adhesive at 80%:20% mixture have a calorific value of 11.22 MJ/kg and a density of 0.565 g/cm^3 (Nurdin et al., 2018). Carbonization process can increase the calorific value of tibarau sugarcane biobriquettes at 300^{o}C (Nurdin et al., 2019). The calorific value of areca fiber briquettes at a concentration of 80%:20% obtained a calorific value of 12.35 MJ / kg and a density of 0.318 g/cm^3 (Hasanuddin et al., 2020).

Carbonization or pyrolysis processes in briquetting can improve combustion properties. Pyrolysis is a thermal decomposition process that occurs in the absence of oxygen, and depending on the heating rate is categorized into fast, slow, intermediate, and flash pyrolysis (Guedes et al., 2018). Research on pyrolyzed palm shells yielded only 46.68% at a temperature of 400 C and this will increase the physicochemical properties of charcoal and its combustion reactivity (Wang et al., 2018). The carbonization process of palm shells can change the physical properties and increase the calorific value (Jelita et al., 2022). Biomass generally differs in its chemical and physical properties, thus influencing its response to carbonization or optimal pyrolysis conditions (Ngene et al., 2024). The amount of heat applied to the carbonization process removes volatiles from the palm kernel shells as the processing temperature is increased and color changes occur (Ikubanni et al., 2020). The decomposition of waste into charcoal, water vapor and volatile organic compounds can be done by carbonization process (Haridan et al., 2020). Carbonization of raw materials for briquette production allows to increase the calorific value and fixed carbon content of the briquettes (Kipngetich et al., 2023).

Based on several studies on the carbonization of palm shells as briquette materials, further research development is needed by optimizing the carbonization process with a briquette-making formulation so that the optimum calorific value is obtained. In the development of this briquette biomass energy source through experimental research with carbonization treatment of palm kernel shells with the aim of increasing the calorific value of the briquettes. The success of conducting experimental studies that obtained the quality of briquettes made from palm kernel shell charcoal became a sustainable solid fuel innovation. Furthermore research can ensure the sustainability of energy utilization that can have an impact on the environment.

2. Research Methods

In outline, this research was carried out in several stages according to research procedures focused on technical laboratory experimental research in an effort to find the optimal concentration of biomass briquette raw material composition and adhesive. The technical parameters of the briquetting process need to be taken into account, including the compressive strength of the briquettes, particle grain requirements, composition and mixing percentage. Figure 1 shows the process of making PKSC briquettes.

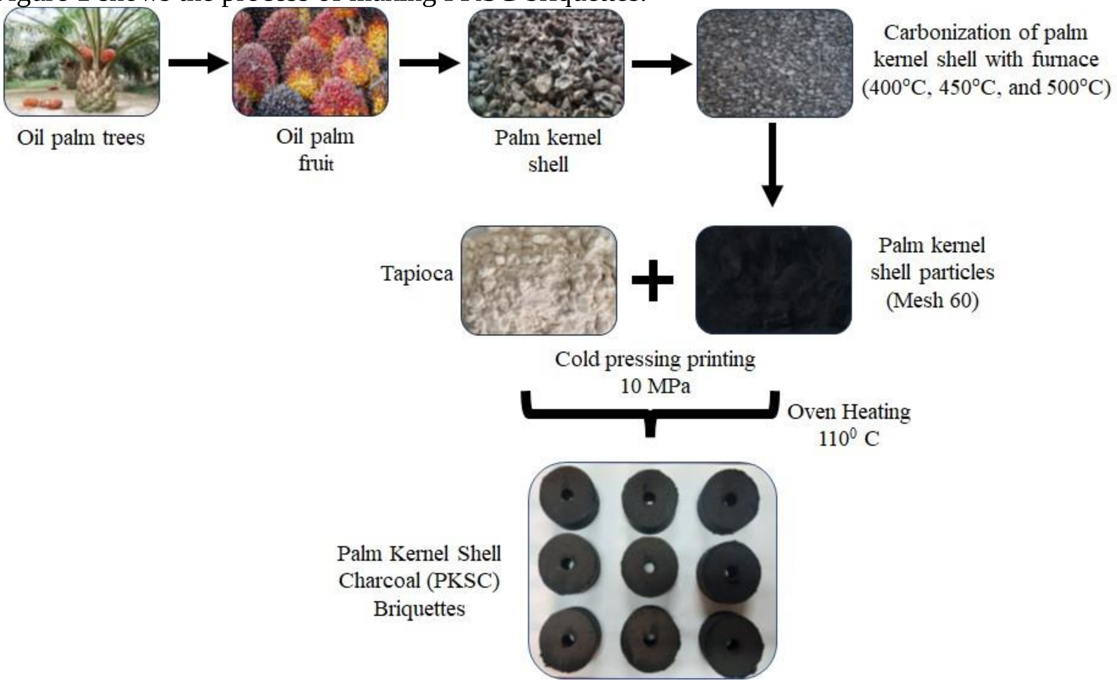

Fig. 1. Preparation of palm kernel shell charcoal (PKSC) briquettes

Then the palm kernel shells are cleaned by washing the fibers that are still attached to the palm kernel shells. Next, drying is carried out by drying in the sun for several days. The dried palm kernel shells are further processed for carbonization or pyrolysis by using a furnace. The temperature used varies, ranging from 400°C; 450°C; and 500°C with a holding time of 1 hour. There is a change in color after the carbonization process, where initially the brown palm shell turns into black. This shows that the charring process on palm kernel shells using the carbonization method has been carried out. Wang's research (Wang et al., 2018) became the basis for selecting the carbonization temperature used, where the research stated that the biomass carbonization process was carried out at a temperature of 400 °C to 700 °C. The carbonization process of oil palm shells at high temperatures tends to increase the number and diameter of pores (Hyväluoma et al., 2018) which has an impact on calorific value and volatiles.

The palm kernel shells that have finished the charring process are then ground and mashed with the Crushing and Grinding stage using the Top Grinding tool. Raw materials that have been refined in the sieving process using a sieve size of 60 mesh or 250 microns. The concentration of palm kernel shell charcoal in making briquettes used is 75%wt; 80%wt; 85%wt to 90%wt.

Biomass briquetting is always combined with the use of adhesives, which in this study used tapioca adhesives. The use of tapioca adhesive results in good particle cohesion (when only water is added) (Bazargan et al., 2014). The concentration of adhesive in biomass briquette making was 10%wt; 15%wt; 20%wt; 25%wt. The concentration of the mixture of palm shell charcoal and tapioca that has been prepared is then put into a cylindrical mold. The briquette molding process uses a hydraulic mold with a pressing pressure of 10 MPa. Studies have shown that the combination of diverse biomass materials can improve the quality of the compacted briquettes (Cui et al., 2021). Furthermore, the briquettes are dried by drying in the sun for 4 days. The dimensions of the molded briquettes are 55 mm in diameter and 29 mm in height with a hole in the middle measuring 11 mm (Figure 2).

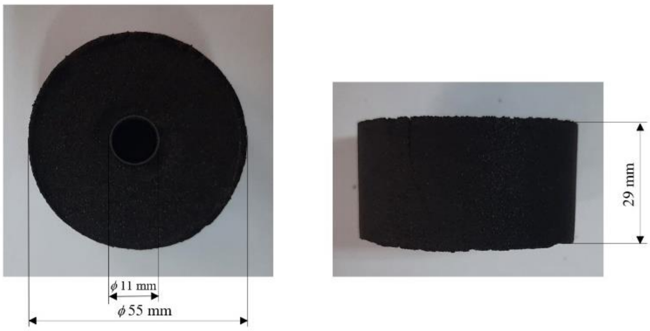

Fig. 2. Dimensions of PKSC Briquettes

The research design conducted in analyzing the calorific value of palm kernel shell charcoal briquettes is guided by laboratory experimental research techniques. The next process is to heat the briquettes using an oven at a temperature of 110^o for 1 hour and weigh the initial condition of the briquettes (m_a) as water absorption test data. After completion, the briquettes are removed from the oven and reweighed (m_s). Furthermore, samples are taken for the calorific value test from some of the briquettes at each concentration.

Furthermore, the calorific value of palm shell charcoal briquettes is tested using the Boom Calorimeter Analyzer LECO AC500. The data analysis technique used is descriptive statistical analysis, where the results are in the form of quantitative data that will be made in the form of a table and displayed in the form of a graph. Furthermore, describe or illustrate the test data in the form of a narrative that is easy to read and understand.

This study focused on obtaining the characteristics and quality of palm kernel shell charcoal briquettes carbonized at various temperatures. Carbonization efficiency in the form of yield on briquettes can be measured from the mass before carbonization and the mass after carbonization. Analyzing the variation of mixture composition and treatment parameters as an indicator of needs. Theoretically, mathematical calculations can be obtained for the calorific value of PKSC briquettes. So that from all the tests carried out, the average calorific value of PKSC briquettes can be known. Then compare the results of the calorific value obtained from the research with the SNI 01-6235-2000 standard (SNI, 2000). It is hoped that this can be a solution to alternative energy sources as solid fuel.

3. Results and Discussions

3.1 Density of briquettes

The density of briquettes is one of the key factors affecting their combustion performance, durability and usability. High-density briquettes contain more fuel per unit volume, resulting in higher calorific value and greater energy and longer burning (Kers et al., 2010). In general, the average mass of briquettes produced for each variation and also the use of different adhesives and the mass of PKSC briquettes obtained is close to the same. Average briquette mass (m) is 51 g and the volume of the briquette (V) is 66.11 cm^3 obtained from the dimensions of the molded briquette. Measurements are carried out after the drying treatment process using an oven at 110^{o}C for 1 hour. Calculation of briquette density is based on the mass of briquettes after baking and measurement of briquette volume based on the dimensions of PKSC briquette printing results. From the research calculations carried out, the density of PKSC briquettes for all variances has the same value approach of 0.77 g/cm^3. In research (Osei Bonsu et al., 2020) which produced a palm shell briquette density of 1.22 g/cm^3 where the traditional pyrolysis process only uses a kiln (furnace). When compared, the research conducted shows the density values obtained are lower than the results of Osei Bonsu et al., 2020. High-density briquettes tend to burn more slowly because oxygen has difficulty penetrating their interior. Conversely, less dense (porous) briquettes will burn quickly due to better airflow. Biomass density is a factor that can lead to higher, more stable and consistent combustion rates (Oduro et al., 2024).

3.2 Biochar yield in Pyrolysis

In this study, carbonization was carried out at three different temperatures, namely 400 ^{o}C; 450 ^{o}C; and 500 ^{o}C. This process will produce biochar, bio-oil, and gas. However, the focus is only on the biochar product. The palm kernel shells are weighed first before carbonization. After the carbonization process is complete, the palm kernel shells that have become charcoal are weighed again. From the difference in mass obtained, the yield produced (biochar yield).

Table 1 - Pyrolysis products yield

Temperature (^{0}C)	Biochar yield (wt%)
400	57.86
450	63.50
500	66.23

Pyrolysis is carried out as a function of temperature that produces biochar yield, as shown in Table 1. The biochar yield increased from 57.86% to 66.23% in the 400 to 500 °C temperature range. This is because there is still a slow and complete decomposition of lignocellulose components at higher temperatures, resulting in an increase in biochar yield. In addition, oil palm shells are rich in lignin and cellulose, which produce high biochar yield at a temperature of 500 °C.

The results obtained from pyrolysis are from the study (Cai et al., 2020), and the biochar yield is preferred at lower heating rates and low temperatures. Biochar yield in slow pyrolysis will produce as much as 60-70 wt% at 440°C and 470°C (Cai et al., 2020). By the results approach obtained from the study (Onokwai et al., 2023), the optimal biochar yield (40.5 wt%) was achieved at a palm kernel shell pyrolysis temperature of 357°C. Temperature and heating rate as pyrolysis operating parameters will significantly affect the quantity and quality of biochar yield (Lee et al., 2017). From the research (Selvarajoo & Oochit, 2020) it was stated that the highest biochar yield characteristic was 54.83 wt% at a temperature of 300 and continued to decrease to a temperature of 500, namely 29.93 wt%, indicating the influence of pyrolysis temperature.

3.3 Calorific Value

In finding a physical form/model of solid fuel of palm shell charcoal briquettes, then from a number of briquettes obtained, further testing and treatment and selection will be carried out. From all the briquettes obtained, analysis was carried out using a physical chemical approach and observation. A very important test in this context is to determine the combustion calorific value using a Bomb Calorimeter.

Based on the tests on the Bomb Calorimeter, the calorific value of the briquettes was obtained as shown in Table 2. The calorific value obtained is based on the calculation of test data. The results of this study indicate a tendency to use binders in briquettes. Briquettes with the use of a large amount of binder have an impact on low calorific value. This study recommends an optimum mixture in making briquettes, namely 85% raw material and 15% binder at carbonization temperature of 400^{o}C . This study proves the influence of the amount of binder used to produce briquettes as solid fuel. In addition, the impact of the carbonization process on the briquette raw material on the resulting calorific value. Figure 3 shows a graph of calorific value based on carbonization temperature. From the graph in Figure 3, it can be seen that there is a difference in calorific value based on the mixing concentration. Increasing the calorific value of briquettes by adding adhesives results in high volatile content and lower ash content (Made Mara et al., 2024).

Table 2 - Calorific Value of PKSC Briquettes

Carbonization temperature	Material of Briquette Mixture		Calorific Value
(^{0}C)	PKSC	Tapioca	(Mj/kg)

400	90	10	25,03
	85	15	25,86
	80	20	24,46
	75	25	24,68
450	90	10	25,04
	85	15	24,75
	80	20	24,69
	75	25	24,81
500	90	10	25,72
	85	15	24,59
	80	20	25,04
	75	25	24,92

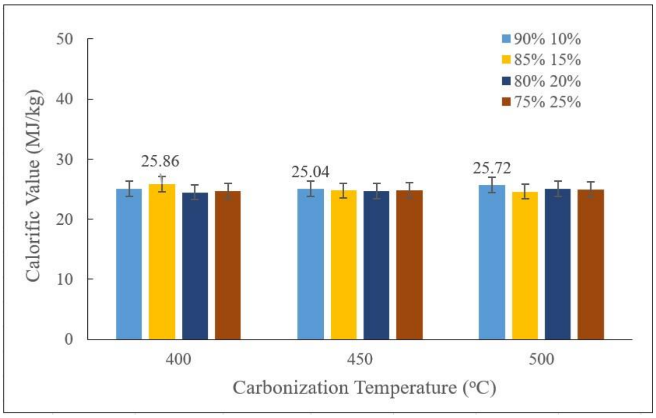

Fig. 3. Graph of calorific value of PKSC briquettes based on carbonization temperature

Calorific value test results of PKSC briquettes with a concentration ratio of 85%:15% using tapioca adhesive, the highest value was 25.86 MJ/kg at 400°C carbonization. The results of this calorific value test show the effect of the carbonization process on briquette raw materials. The results of this heating value test show the effect of the carbonization process on the briquette raw material. At a mixture concentration of 85%:15% with a carbonization temperature of 400 °C, the highest PKSC briquettes volatille matter reached 37.30% and Fixed Carbon only 52.17%, indicating that the highest calorific value. According to (Vega et al., 2019) stated that the high fly content of briquettes is very beneficial because it promotes rapid combustion, which is beneficial for fuel efficiency. High volatile matter and fixed carbon content make the solid fuel reactive and easy to ignite at low temperatures, resulting in high calorific value (Kamaruddin et al., 2023).

Several studies that have been conducted by other researchers also show the effect of carbonization or pyrolysis on the heating value produced. Carbonized palm kernel shell briquettes have a calorific value of 26.54 MJ/kg as an alternative solid fuel (Mbada et al., 2016). The calorific value of PKSC briquettes produced in this study was lower than that of bituminous coal and anthracite but higher than that of firewood, peat and lignite coal. Figure 4 compares the calorific value of palm kernel shell charcoal briquettes produced from this study with that of some major solid fuel types adopted from Khurmi (Khurmi & Gupta, 2006).

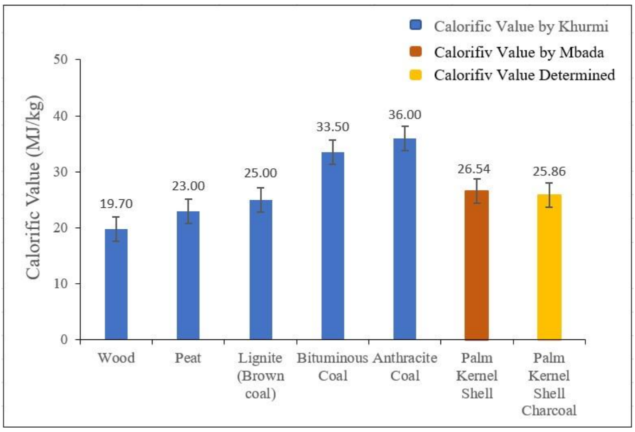

Fig 4. Calorific Values of Some Selected Solid Fuel

The carbonization process aims to produce smokeless fuel in the flame, and remove some of the water content (Mbada et al., 2016). The effect of carbonization temperature shows that the amount of carbon produced gets smaller the higher the temperature but there is an increase in tar produced. According to research (Zanjani et al., 2014) (Haridan et al., 2020) that high carbonization temperatures result the more it tends to reduce the calorific value, volatile matter, water content, and fixed carbon but the ash content of the briquettes tends to increase. From this research, the calorific value was obtained according to the SNI 01-6235-2000 standard (SNI, 2000) so it is possible to be an alternative as a solid fuel. A comparative analysis of the feedstock revealed the specific characteristics of the material, with palm kernel shell charcoal-based briquettes being superior in terms of calorific value. The findings of this study shed light on the importance of the feedstock carbonization process in impacting biochar yield, which in turn affects calorific value. In accordance with the statement in research (Guo et al., 2020) that very important properties to be determined for briquettes are the calorific, chemical, physical and mechanical properties that can affect their respective applications. The information is important as details that still need to be developed in further research to find mixed raw materials (Calliandra wood) and the use of different binders.

Biomass briquette research is an alternative solid fuel in finding solutions to meet energy needs. According to research by (Sithole et al., 2023), that the improvement of solid waste management due to organic waste can be used as part of the main feedstock (biomass and binder) by performing torrefaction and densification processes. The sustainable development of renewable energy engineering is an advancement in energy utilization in a highly influential and interdependent environment. The certainty of the sustainability of energy utilization greatly impacts the environment. According to (Gibson et al., 2017), energy derived from living plants (biomass) is renewable energy as a solution in meeting energy needs and can reduce environmental impacts. Sustainability is expected in developing biomass renewable energy as an alternative to solid fuel. In compensating and saving the environment, there needs to be sustainability in developing biomass renewable energy in briquette technology (Yustas et al., 2022). By utilizing palm kernel shell charcoal as a briquette material to obtain solid fuel so that the negative impact on the environment can be overcome.

4. Conclusion

The study successfully utilized palm kernel shell solid waste by carbonization process into briquettes as solid fuel. Differences in carbonization temperature have an impact on yield and heating value in the presence of various mixing concentrations of palm kernel shell charcoal and tapioca. Carbonization and densification processes can improve the management of solid waste as the main biomass feedstock. By carrying out the carbonization process on palm kernel shells, there will be an improvement in the quality of briquettes. In addition, the effect of the comparative concentration of raw materials also has an impact on the calorific value produced. The making PKSC briquettes is one of the renewable energy developments in realizing sustainable alternative solid fuels. In the future, further research needs to be developed by blending the raw materials and using different binders. Gradually, the use of coal will be reduced as fuel, so there is a need for various researches in the search for biomass materials that can be further processed to produce energy sources.

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