PERFORMANCE TEST OF COCONUT SHELL GRINDING MACHINE FOR PYROLYSIS PROCESS

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***Abstract**. Coconut shell is a solid waste of biomass from processed coconuts separated from the flesh. Coconut shells can be reprocessed into products of high economic value. Coconut shells can be processed for bio-oil production via high-temperature pyrolysis. In the pyrolysis process, the coconut shell raw materials are reduced in size to facilitate combustion. The aim of this research was to test the performance of the modified coconut shell grinding machine, determine the effect of water content on the milling process, achieve coconut shell sizes of 3, 5, and 10 mm to enhance the pyrolysis process, and analyze the economics of grinding machine engineering. The size reduction process was carried out using a custom-designed coconut shell grinder that was altered in its sieve section. The sieve sections had diameters of 10, 5, and 3 mm. The coconut shell to be ground had a moisture content of 8–10%. The grinding machine capacity varies with each size, namely 10 mm, 5 mm, and 3 mm, achieving throughput rates of 14.892 kg/h, 7.214 kg/h, and 2.94 kg/hour, respectively. The resulting yield was notably high, ranging from 95 to 96.780%, and the associated yield loss remained low, between 3.2% and 4.8%. During the material size tests, the working RPM was observed at 630.6 for 10 mm, 711.2 for 5 mm, and 1017.18 for 3 mm, and these RPM variations influence the grinding speed.*
***Keywords:** coconut shell; pyrolysis; grinding machine; capacity; yield*

1. Introduction

Coconut shells represent residual material resulting from the extraction of coconut milk after the removal of the coconut meat during processing. Coconut shells are generally used for fuel, household purposes or souvenirs (Nustini & Allwar, 2019). Coconut shells are downstream coconut products that are still often considered solid waste and can cause environmental problems because they are difficult to decompose or degrade naturally in the environment (Sa'diyah *et al*., 2018). Agricultural biomaterials and agro-waste such as coconut shells have found many applications in technological advancement, including the production of activated carbon, purification, energy sources, reinforcement, fillers, and various other applications (Ikumapayi & Akinlabi, 2019b). Coconut shells are part of the hardwood group with a water content of around

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6-9% (dry weight) which is composed of lignin, cellulose and hemicellulose. The chemical composition of the coconut shell includes 29.4% lignin, 27.7% hemicellulose, 26.6% cellulose, 8.0% water, 0.6% ash content, 4.2% extractive components, 3.5% uronic anhydrous, and 0.1% nitrogen (Suhardiyono, 1988). The coconut shell is a solid waste of biomass from the processed coconut separated from the flesh. There are quite a few properties that make coconut shell a good alternative fuel as it exhibits quite good thermal diffusion characteristics (Sudding & Jamaluddin, 2016).

There is a significant amount of coconut shell waste present in Indonesia, particularly in Payakumbuh City, Limapuluh Kota Regency, and West Sumatra. Coconut shells are a cost-effective resource due to their widespread availability in more than 90 countries worldwide (Rout *et al.*, 2016). Coconut shells can be reprocessed into products that have high economic value. In order to increase the value of coconut shell, the pyrolysis process uses high temperatures to convert the waste into biofuel. Coconut shells are obtained from the coconut processing industry and have not been utilized optimally, therefore, the pyrolysis process is the best way to increase its value (Rout, 2013). Throughout the pyrolysis process, numerous reactions take place, involving substances initially present in the raw material, along with intermediate compounds and end products (Kaczor *et al.*, 2020). Over the past decade, the feasibility of biomass pyrolysis as an energy conversion process has been demonstrated, primarily owing to its environmentally friendly low-carbon footprint. The resulting pyrolytic products, including biochar, bio-oil, and biogas, have diverse applications and play a role in fostering industrial, commercial, and economic growth in our society (Azeta *et al.*, 2021).

In order to enhance the efficiency of the pyrolysis process, the coconut shell raw material is resized to aid combustion. This resizing is achieved through coconut shell grinding using a specially adapted grinder equipped with sieve sections measuring 10 mm, 5 mm, and 3 mm in size. In the pyrolysis technique, several parameters affect the pyrolysis process: the pre-treatment of the biomass, the moisture content, and the particle size of the material (Novita *et al.*, 2014). It is specially designed and modified to do the job of reducing the size of coconut shells. The research was conducted in order to grind coconut shells in order to make nano carbon with an average size of 2 - 10 mm, and it is hoped that the design of this tool will enable the reduction of the size of the coconut shell so that it will be easy to burn using the pyrolysis technique (Ikumapayi & Akinlabi, 2019a). The design of this coconut shell grinding machine has not been done much in Indonesia but the most widely used is the design of a charcoal grinder. The basis for designing this machine was a charcoal grinder design. In the selected design concept, a hopper is used as a medium for crushing charcoal, a hammer mill is used to crush charcoal, a frame is constructed, pulleys and belts are utilized, and fuel motors are utilized to fuel the machine (Ariesta *et al*., 2022). The grinding time of coconut shell powder into nanoparticles and the effect of effective grinding time are being studied (Bello *et al*., 2015).

The aims of the research were to test the performance of the modified coconut shell grinding machine, determine the effect of water content on the milling process, achieving coconut shell sizes of 3 mm, 5 mm, and 10 mm to enhance the pyrolysis process, and analyze the economics of grinding machine engineering.

2. Methods

The research was conducted at the Politeknik Pertanian Negeri Payakumbuh. Coconut shells are dried to a water content of 8-12 %. The water content of coconut shells must be low to facilitate and shorten the grinding time. Coconut shell drying is carried out for 14 days using a drying house with a temperature of 60-80 ^{o}C. The coconut shells were dried in an electric oven at 50 °C for 5 days to ensure thorough dehydration before the crushing process (Ikumapayi & Akinlabi, 2019b). The coconut shell used can be seen in Figure 1.

Figure 1. Coconut Shell

2.1. Research Prosedurs

The process of making this machine uses a functional design and structural design approach. Functional design explains the function of each component in the machine, while structural design is a way to build the structure of the machine. Several stages of the engine manufacturing process can be seen in the flow diagram in Figure 2.

2.2. Grinding Machine Modification

Modification of this grinding machine is done by modifying the size of the sieve diameter to 3 mm, 5 mm and 10 mm. The primary factors that significantly impact rapid pyrolysis are the velocity of heat transfer and the small particle size of biomass (Novita *et al*., 2022). Experiments were carried out to assess particulate matter using 8 mm and 12 mm sieves, as well as to measure agglomerate pressure at levels of 37 and 47 MPa (Dziedzic *et al*., 2018) . The coconut shell grinding machine has main components including frame, hopper, outlet, pulley and V-belt, hammer mill, filter and 1.5 HP electric motor. The design of a coconut shell-breaking machine includes diverse components like a sprocket safety cover, capacitor, belt cover, electric motor for propulsion, on/off switch, coconut shell breaker sprocket, coconut shell breaker, breaker gear box, and screw adjuster. The machine can break one coconut shell per minute, driven by a 1:50 gear box and a ¾ hp AC motor (Yuliati *et al*., 2019). Coconut shells are roughly chopped to facilitate the grinding process. The crushers were installed on two parallel rotating shafts driven by a spur gear. The power from the electrical motor was transferred to the cutter shaft via a belt drive. Crushing occurs within the crushing chamber and is influenced by tensile, friction, and impact forces during the crushing process (Mohan *et al*., 2021). The modification grinding machine can be seen in Figure 3.

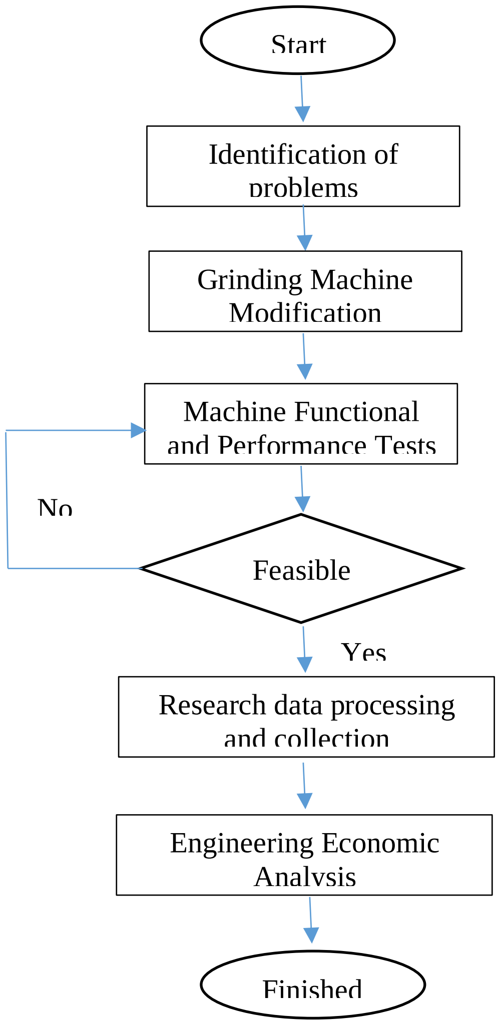

Figure 2. Research flow diagram

This adjustment to the sieve facilitates the grinding of coconut shells for the subsequent processing step. Modification of grinding sieves with sizes of 10 mm, 5 mm, and 3 mm. The sieve model on this grinding machine can be seen in Figure 4.

Figure 3. Grinding Machine

Figure 4. Sieve Size 3 mm, 5 mm and 10 mm

2.3. Machine Performance Test

The machine performance test is conducted to obtain performance data from the engine that has been made. The equipment that is used for measuring the speed is a tachometer and a stop watch. The data to be obtained in performance testing (1-4):

1. $\text{Inflow Capasity}\ (\frac{\text{kg}}{\text{hour}}) = \frac{IW}{\text{t}}$ (1)
2. $\text{Grinding Capasity}\ (\frac{\text{kg}}{\text{hour}}) = \frac{GW}{\text{t}}$ (2)
3. $\text{Rendement}\ (\%) = \frac{GW}{\text{IW}} x\ 100\%$ (3)
4. $\text{Losis}\ (\%) = \frac{BH}{\text{IW}} x\ 100\%$ (4)

Explanation:

IW: Initial weight (kg)

GW: Grinding weight (kg)

LW: Lost weight (kg)

t: Time (hour)

2.4. Engineering Economic Analysis

Engineering economic analysis is carried out to assess or see the feasibility of a tool from an economic point of view. The cost calculation analysis carried out involves the calculation of fixed costs, variable costs, basic costs, and break event points (BEP) (5-8).

1) *Fixed Cost (FC)* (5)

FC = D + I

D = (P - S) / N

$I = r \times (P + S)/2$

2) *Variable Cost (VC)* (6)

VC = PP + Bo

PP = 1,2 % (P – S) / 100 hours

Bo = Wop / Wt

3) *Basic Cost (BC)* (7)

BC = {(FC/n) + VC} /C

4) *Break Event Point* $BEP = \frac{BT}{R-(\frac{BTT}{Kp})}$ (8)

3. Results and Discussion

3.1 Modification Coconut Shell Grinding Machine

Coconut shells can be processed for bio-oil production through a high-temperature pyrolysis process. In the pyrolysis process, coconut shell raw materials are reduced in size to facilitate combustion. Before grinding, the coconut shell is dried for 14 days in a drying house until the moisture content is 10–12%. To obtain coconut shell powder, the mature coconut shell is initially cleared of any remaining pithy material or subjected to sanding (Jabal *et al*., 2016). The coconut shell is then roughly chopped to make the grinding process easier. Shell grinding was carried out using a hammer mill-type shell grinder, which was modified in terms of the sieve size. The size of the sieve on the grinder is made with three holes sizes, namely 3 mm, 5 mm, and 10 mm.

The difference in sieve size is made to make it easier to obtain material sizes that suit the needs of the shell pyrolysis process into bio-oil, charcoal, and gas. The smaller particle size of the material, which is 0.3–1.5 mm, can increase the amount of bio-oil produced (Shen *et al*., 2009). Drying biomass to reduce water content using hot air flow at a temperature of 150 °C (Wang *et al*., 2017). The particle size of the materials usually used after cutting is 10–30 mm, and grinding is 0.3–1.5 mm (Sun & Cheng, 2002). The study material underwent grinding using two working sieves with sizes of 8 mm and 12 mm to examine how the fragmentation of the raw material affects the quality of the briquettes produced during the agglomeration process (Dziedzic *et al*., 2018).

Coconut shell grinding machine is a type of hammer mill. This hammer mill uses a high-speed rotating disc on which a number of hammer rods are swung outward by centrifugal force. The top feed material is then centrifugally crushed by being struck between the hammer rods around the rim of the cylindrical casing. The material will be crushed by the impact between the hammer and the high-speed material, and the hammer crusher has a simple structure, a high reduction ratio, high efficiency, etc (Kumar *et al*., 2017). There is a machine that uses a 150 HP power plant and a 3100 rpm engine speed in the process of making coconut shell powder, which uses 16 knife blades to rotate and grind coconut shells into fine powder. During the processing of coconut shells, each machine is capable of producing 1 ton of coconut shell powder per day and operates every 16 hours of the day (Surasno & Ihlas, 2019).

The size reduction process was conducted using a coconut shell grinder specially designed and modified in the sieve section. Low water content facilitates the process of size reduction in the coconut shell. The coconut shell grinding process can be seen in Figure 5.

Figure 5. Grinding Process

The coconut shell is usually chopped in order to reduce its size so that it can be used properly, and for the next step, it can be used properly and easily (Ariffin *et al*., 2020). It is believed that the design of the coconut shell and husk chopping machine was carried out in two stages: the process of cutting the shell and husk into smaller sizes and then refining the size according to the needs of the customer (Ariffin *et al*., 2020). The advantages that coconut shell powder has include low material costs, stone ability, a quality that is very good, high physical strength, low density, low machine abrasion, and an environmental friendliness (Sugumar *et al*., 2021).

Coconut shell powder appears to be a compelling option because of its chemical composition. The review investigates the development of polymer composites reinforced with coconut shell fibers, encompassing manufacturing processes, methodology, and the assessment of mechanical properties and thermal analysis, as well as potential applications (Udhayasankar & Karthikeyan, 2015). Coconut shell powder offers the advantage of higher thermal degradation temperatures due to its high lignin content compared to most other natural fillers (Kirby *et al*., 2019). Figure 6 exhibits coconut shells that have been subjected to milling, resulting in a range of different sizes.

(a) 10 mm (b) 5 mm (c) 3 mm

Figure 6. Coconut Shell Particle Size

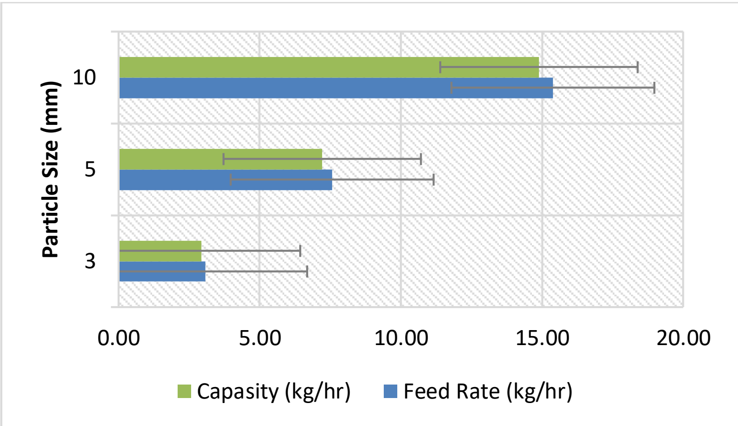

Figure 7. Evaluating the difference between the feed rate and the machine's capacity

3.2 Performance Test Coconut Shell Grinding Machine

The machine performance test was undertaken to determine whether the machine was functioning properly, if the feed rate was sufficient, and if the machine capacity was adequate to mill coconut shells. The machine feed rate value is higher than the machine capacity value when compared to the machine capacity. The duration of milling is directly correlated with particle size distribution and inversely correlated with the surface area of particle size (Bello *et al*., 2015).

Grinding coconut shells is a more challenging task compared to coconut charcoal due to the hardness of the wood. The shell's chemical composition closely resembles that of hardwood, with a higher lignin content and a reduced cellulose content. Despite being utilized for their flesh, water, and oil, approximately 99% of coconut shells are typically discarded and incinerated (Liyanage & Pieris, 2015).

Several series of tests were performed on the fabricated ball mill to assess its grinding capability and reproducibility with coconut shell chips 1 mm, 10 mm, and 1–10 mm in diameter (Rosi & Viridi, 2018). It is important to note that when a material size of 10 mm is used, the feed rate value is higher than when the material size is 3 mm or 5 mm. The values of the feed rate and machine capacity can be seen in Figure 7.

Determine the feed rate and machine capacity by employing formulas (1) and (2) for calculation. According to the feed rate values for each particle size of 10 mm, 5 mm, and 3 mm, the particle size feed rates are 15.39 kg/hour, 7.57 kg/hour, and 3.09 kg/hour, respectively. The capacity of the grinding machine for each size of 10 mm, 5 mm, and 3 mm is 14.9 kg/hour; 7.2 kg/hour; and 2.9 kg/hour. The highest grinding capacity is achieved with a sieve diameter of 10 mm. The ball mill yielded powder from coconut shell at rates of approximately (26.07 ± 1.2)%, (22.69 ± 1.58)%, and (16.24 ± 0.52)% for coconut shell chips of 1 mm, 10 mm, and 1-10 mm, respectively, during a 30-minute testing period. The consistent results demonstrate the high reproducibility of the ball mill, suggesting its potential as a machine for preparing coconut shell powder (Rosi & Viridi, 2018).

Meanwhile, in determining yield and yield loss, utilize formulas (3) and (4). The yield is high enough, 95–96.78%, and the loss is low, 3.2%–4.8%. The difference in yield is caused by the size of the sieves in the machine. The larger the particle size of the material, the higher the yield will be. The yield of fine materials will be lower, and in the same manner, the working capacity will be lower as well. The yield of each material size is shown in Figure 8.

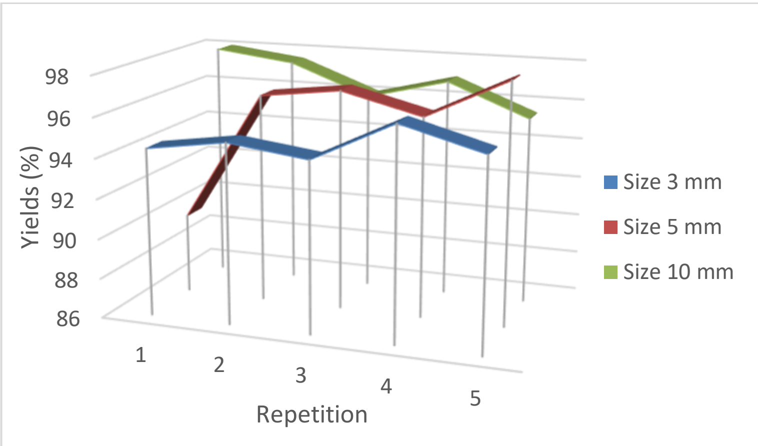

Figure 8. Comparison of yield on each material size

The performance and output of coconut shell crushing are significantly impacted by the rotational speed of this grinding machine. The variation in rotation speed is attributed to the differences in sieve diameters sizes, with the highest rotation speed, reaching 1017.184 RPM, occurring when processing 3 mm material. This is because the 3 mm material, being the smallest size, demands a higher rotation speed compared to other material sizes. Differences in rotation speed can be seen in Figure 9.

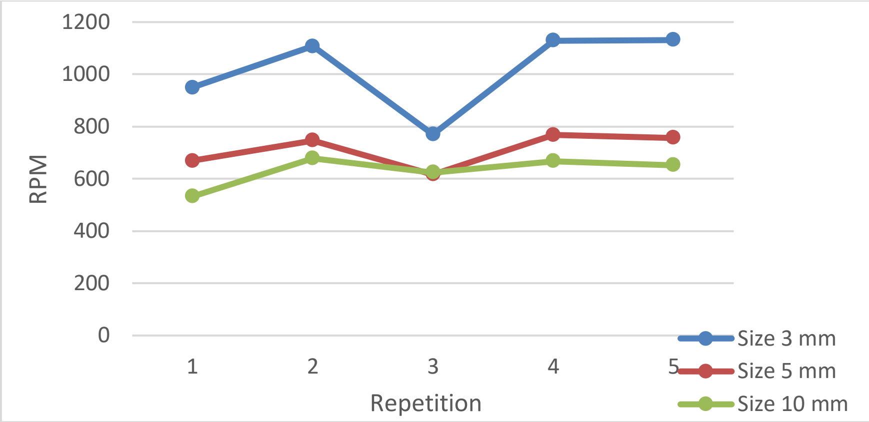

Figure 9. Machine Rotation Speed Comparison

The working RPM during the test for material sizes 10 mm, 5 mm, and 3 mm were 630, 711, and 1017.184 RPM, respectively. That RPM difference affects the grinding speed. The rotation speed of the pulley depends on the size of the sieve diameter.

Table 1. Calculation of Engineering Economic Analysis

Asumpsions	**Engineering Economic Analysis**		
	Particle Size 10 mm	**Particle Size 5 mm**	**Particle Size 3 mm**
Machine selling price (P) (Rp)	7500000	7500000	7500000
Final value (10%.P) (Rp)	750000	750000	750000
Estimated engine life (years)	5	5	5
Interest rate (%/year)	10	10	10
Working hours per day (hours)	8	8	8
Number of working days per year (days)	300	300	300
Hours worked per year (hours)	2400	2400	2400
Operator Wages (days)	100000	100000	100000
Capacity (kg/hour)	14.892	7.214	2.940
Machine Rental (Rp/kg)	2000	4000	6000
Fixed Cost (Rp/year)	**1837500**	**1837500**	**1837500**
Variable Cost (Rp/hour)	**13400**	**13400**	**13400**
Basic Cost (Rp/kg)	**951.22**	**1963.63**	**4818.24**
Break Event Point (BEP) (kg/th)	**1670.17**	**857.64**	**1274.12**

3.3 Engineering Economic Analysis

There are several components to the cost of making this machine, including the cost of purchasing materials, the cost of renting workshops and equipment, the cost of labor, and so on. It is necessary to utilize technical economic analysis in order to calculate machine operational cost analysis by taking into account fixed costs, basic costs, and break event points. To simplify the computation of technical economic analysis, apply formulas (5) to (8). These assumptions can be seen in Table 1.

Referring to Table 1, it is evident that the technical economic analysis of this grinding machine, when applied to different material sizes, results in varying fundamental costs and break-even points. Specifically, the 10 mm material size incurs a cost of Rp. 952.22/kg and a BEP of 1670.17 kg/year, establishing a foundational cost. In contrast, the 5 mm material size carries a cost of Rp. 1963.63/kg and a BEP of 857.64 kg/year, while the 3 mm material size is associated with a cost of Rp. 4818.24/kg and a BEP of 1274.12 kg/year. The most economical milling costs for coconut shells occur with a 10 mm material size, while the most favorable break-even point (BEP) is achieved when milling with a 5 mm material size.

Based on this economic evaluation, it can be inferred that the fundamental milling expenses for coconut shells remain relatively high, indicating a necessity for several machine enhancements to streamline the coconut shell grinding process. Many internal problems have prevented coconut from being utilized to its full potential financially. These include production problems, processing problems, marketing problems, and institutional problems. Efforts are being made to empower human resources, particularly through technology (Yuliati *et al*., 2019).

4. Conclusions

The coconut shell grinding machine has main components including frame, hopper, outlet, pulley and V-belt, hammer mill, filter and 1.5 HP electric motor. The highest grinding capacity is achieved with a sieve diameter of 10 mm. The yield is high enough, 95–96.78%, and the loss is low, 3.2%–4.8%. The difference in yield is caused by the size of the sieves in the machine. The variation in rotation speed is attributed to the differences in sieve diameters sizes, with the highest rotation speed, reaching 1017.184 RPM, occurring when processing 3 mm material. The most economical milling costs for coconut shells occur with a 10 mm material size, while the most favorable BEP is achieved when milling with a 5 mm material size.

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