The Effect of Modification Vertical Partition On Kiln Drum Performance For Coconut Shell Carbonization

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Abstract. Coconut shell as an organic residue that could be re-utilized to charcoal raw material through carbonization or pyrolysis process. Kiln is a thermally insulated chamber that produces enough temperatures to complete some process such as carbonization. This study aimed to conduct a performance test of modification drum kiln with vertical partition for coconut shell carbonization. These partitions were added in order to limit the direct contact between coconut shells and husk, thus the temperature inside each chamber can be easier to maintain. The data obtained with placing the thermocouple in five places, while also measure wind velocity, relative humidity and environment. The drum kiln has 6 main components, which are pyrolysis main chamber, initial combustion chamber, air inlet, chimney, unloading and vertical partition. Optimum performance of kiln with vertical partition was in average temperature of 295.67 \(^\circ\)C, maximum temperature 531.33 \(^\circ\)C, charcoal yield 21.67 - 26.80\%, carbonization time 78.33 minute and calorific value of 7,505.33 kcal/kg. Vertical partition able to limit and control kiln temperature also increased pyrolysis rate as well as charcoal yield.

Keywords. Kiln, Pyrolysis, Carbonization, Coconut Shell.

1. Introduction

Coconut (\textit{Cocos nucifera}) is a famous tropical fruit originated from tropical region. It is belonging to the palm family. According to the statistical data by the Asian Pacific Coconut Community (APCC), the global coconut area in 2015 was 11.98 million ha, while 75\% of the coconut world production comes from Indonesia, Philippines, and India\textsuperscript{[1]}. The major product of coconut is coconut flesh, coconut water and others biomass residues i.e. coconut shell, husk and leaves. The utilization of coconut residue especially coconut shell still limited and many of them became wasted. Coconut shell has a strong structure and harder to be decomposed by microorganisms. It is slightly similar with wood in terms of composition that contains lignin (29.4\%), hemicellulose (27.7\%), cellulose (26.6\%), extractive component (4.2\%), anhydride (3.5\%), water (8\%), ash (0.6\%), and nitrogen (1\%)\textsuperscript{[2]}.

Carbonization is one of the pyrolysis processes that decomposed material using heat, with more than 150\(^\circ\)C in temperature and limited or without oxygen. The material will crack out in to carbon (C), carbon monoxide (CO), methane, water vapor, hydrocarbon gases, and the other volatile substances. Charcoal is a pure carbon formed in pyrolysis process. Processing the coconut shell into a charcoal using pyrolysis process will certainly add its calorific value, compared with the original coconut shell. According to\textsuperscript{[3]}, coconut shell charcoal can have a calorific value up to 7.332 kcal/kg, while the original coconut shell can only produce 4.950 kcal/kg.
Drum kiln is one of the simple pyrolysis tools that commonly used by society to produce charcoal. Pyrolysis process occur inside the closed drum with a limited oxygen supply from air inlets in the side and below of the drum. Heating energy comes from inside the system by combustion of the raw material. Some research about coconut shell kiln already done before. The designed of venturi-drum kiln with optimum capacity of 12.45 kg coconut shell and succeeded to reach pyrolysis temperature up to 908.56 °C [3]. Other design made by metal drum kiln shown the optimum capacity of 11 kg and pyrolysis temperature of 401.80 °C [4]. The result of pyrolysis process highly depends on the pyrolysis temperature occurred in the kiln. This study aimed to design and conduct a performance test of drum kiln with vertical partition for coconut shell carbonization. The vertical partition was added inside the as a modification kiln to limit the direct combustion and high thermal heating and air circulation inside the bulk of coconut shell. Thus, using this vertical partition, the temperature inside each chamber can be easier to maintain.

2. Material and Methods

2.1 Design Approach
As the vertical partition limit the direct contact between the coconut shells, it was expected that the temperature and air circulation in every chamber would also be limited and able to be controlled.

2.2 Tools and Materials
The tools required to make the kiln available on workshop i.e electric welding, grinding, metal cutting, etc. For the performance test were type K thermocouples; autonics recorder; KANOMAX climomaster and scale weight. Materials used to make this kiln were iron plate with 2 mm thickness for the kiln wall and 3 mm thickness for kiln base. The coconut shell and husk were used as the raw material for pyrolysis process.

2.3 Research Procedure
This research started by collecting information regarding coconut shell and pyrolysis process characteristics. Design formulation and analysis were done by using SolidWorks 2016 software. The desired temperature for this slow pyrolysis were 400 °C. The kiln was fabricated in the workshop, and tested for the pyrolysis time, temperature, charcoal yield and calorific value., The performances of kiln with vertical partition and without vertical partition were evaluated. The research procedure can be seen as in Fig. 1.

![Figure 1: Research procedure](image-url)
2.4 Performance Test Parameters
The kiln parameters were determined in order to represent the real functional and structural performance.

(a) Pyrolysis Rate
Pyrolysis time were measured from the first time the loading path closed until the smoke diminished and the charcoal yield were taken from the kiln. Pyrolysis rate is the ratio between the charcoal yield and the pyrolysis time.

(b) Pyrolysis Temperature
Temperature is the most important factor determining the entire pyrolysis process and the charcoal yield result. There were five measurement points; the left, right, and back pyrolysis chambers; kiln wall, and kiln chimney.

(c) Charcoal Yield
The charcoal yield was determined from the percentage of charcoal formed from the coconut shell raw material. It also shown the efficiency of pyrolysis process.

(d) Charcoal calorific value
As the charcoal result is a solid fuel, the calorific value should be tested in order to know the ability of the charcoal to produce energy. Calorific value was tested in Research and Development Center of Forest Products (P3HH) Laboratory, Ministry of Environment and Forestry, Bogor, Indonesia.

2.5 Kiln Performance Test
The performance test was done in several times. The data obtained by placing the thermocouple in several places; each of pyrolysis chamber, kiln wall, and kiln chimney. The wind velocity, relative humidity and environment temperature were also measured by using KANOMAX Climomaster around 1 m in front of the main oxygen inlet. The temperature was recorded every 5 minutes. After the smoke diminished, the charcoal was taken through the unloading door and measured for the further analysis.

3. Result and Discussion

3.1 Functional Design
The main function of kiln is where the pyrolysis process taking places. There should be a uniform temperature distribution inside the kiln to produce a high yield of charcoal. Thus, the initial ignition chamber and some air inlets on the wall provided to support an adequate air flow inside the kiln. The function explanation for the kiln parts is shown in Table 1.

| No | Part                  | Function                                                                 |
|----|-----------------------|--------------------------------------------------------------------------|
| 1  | Initial combustion chamber | A place to ignite the first combustion process inside the kiln.          |
| 2  | Main chamber           | The coconut shell and husk placed inside this chamber. This is also where the pyrolysis process take place. |
| 3  | Air inlets             | Provide limited oxygen so that pyrolysis process can be occurred.       |
| 4  | Chimney                | This part acted as pyrolysis smoke outlet.                               |
| 5  | Unloading              | To take the charcoal yield out from the main chamber.                    |
| 6  | Vertical partition     | This partition was added in order to limit the direct contact between coconut shells and husks. |
3.2 Structural Design
The detail part of the kiln is shown in the Figure 2 below.

(1) Initial combustion chamber
This initial combustion chamber used to ignite the first combustion. There were around 5 cm of coconut shell and husk placed inside this chamber as the first part of the raw material to be burnt. This initial chamber shaped like a hollow tube, with diameter of 100 mm and height of 480 mm.

(2) Main chamber
The pyrolysis process was conducted inside this main chamber. In order to made the proper dimension of the kiln, there were some calculation ensued. Bulk density of coconut shell is 510 kg/m$^3$ [5]. The mass for one batch of pyrolysis is 15 kg and volume of the kiln main chamber was 174 liter.

(3) Air inlets
The base part of the kiln was made of iron plate with 2 mm holes which were distributed uniformly. This main air inlet was not directly in contact with the environment, but it was bordered by the unloading part so that the user can easily control the amount of the air going to the kiln. There were another eight air inlets in the kiln wall, with diameter 0.5 inch. This side air inlet helps the circulation of oxygen right into the main chamber in hope that the temperature would be evenly distributed.

(4) Chimney
This chimney had 100 mm in diameter. The main function was creating a turbulence effect for the high temperature smoke inside the kiln and it would distribute the temperature even more uniform.

(5) Unloading
In order to simplify the process for getting the charcoal out, an unloading part provided downside the main chamber. There was horizontal partition between the kiln main chamber and unloading chamber, which also acted as the base plate with the main air inlet distributed in it. After the pyrolysis process were done, as the horizontal partition removed, the charcoal would fall into unloading chamber and could be taken.
Vertical partition
There were total of four vertical partition in this kiln. It was made from iron plate with 3 mm thickness. There were also some holes created in order to let the heat keep exchanged from one chamber to another as the air flowed. The dimension of each partition was 230 mm x 430 mm.

3.3 Kiln Performance Test
There were two kind of test conducted in this research; performance test for kiln with vertical partition, and performance test for kiln without partition. Each of it has three times different performance tests. The results are shown in Table 2 and 3 below:

| Test   | Initial Mass (kg) | Average Temperature (°C) | Maximum Temperature (°C) | Charcoal Mass (kg) | Yield (%) | Time (min) | Wind speed (m/s) | Environment Temp (°C) | RH (%) | Calorific Value (kcal/kg) |
|--------|-------------------|--------------------------|--------------------------|--------------------|-----------|------------|------------------|------------------------|--------|--------------------------|
| 1st    | 15                | 263.67                   | 512                      | 3.25               | 21.67     | 80         | 0.34            | 31.03                  | 67.57  | 7,603                    |
| 2nd    | 15                | 324.64                   | 548                      | 3.4                | 22.67     | 85         | 0.17            | 29.55                  | 74.35  | 7,518                    |
| 3rd    | 15                | 298.71                   | 534                      | 4.02               | 26.8      | 70         | 0.35            | 28.2                   | 80.6   | 7,395                    |
| Average| 15                | 295.67                   | 531.33                   | 3.56               | 23.71     | 78.33      | 0.29            | 29.59                  | 74.17  | 7,505.33                 |

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|--------|-------------------|--------------------------|--------------------------|--------------------|-----------|------------|------------------|------------------------|--------|--------------------------|
| 1st    | 15                | 254.92                   | 684                      | 2.49               | 17.58     | 85         | 0.3             | 28.33                  | 75.83  | 7,629.00                 |
| 2nd    | 15                | 363.37                   | 626                      | 2.95               | 20.67     | 85         | 0.54            | 28.2                   | 79.15  | 7,318.00                 |
| 3rd    | 15                | 345.27                   | 642                      | 2.72               | 18.15     | 80         | 0.73            | 31.45                  | 64.73  | 7,428.00                 |
| Average| 15                | 321.19                   | 650.67                   | 2.72               | 18.80     | 83.33      | 0.52            | 29.33                  | 73.24  | 7,458.33                 |

Pyrolysis process depends on some factors, such as the raw material composition, properties (density, thermal conductivity, thermal capacity, material permeability), size of particle, temperature and heating rate. Temperature and heating were very important in term of material conversion rate and the result composition of pyrolysis process [6]. The coconut shell was already been crushed into smaller pieces. The vertical partitions were placed in the center of two side air inlets, in order to let all the chamber filled with the same amount of oxygen, as shown in Figure 3.
Kiln with vertical partition had average pyrolysis rate of 0.191 kg/min, little bit higher than the kiln without vertical partition which was 0.182 kg/min. As the vertical partition limit the contact between four chambers of coconut shell, the pyrolysis process would concentrate into each chamber. With lower amount of raw material that should be turned into charcoal, the heat would easily spread inside each particular chamber and the pyrolysis rate and time would be shorter, thus the pyrolysis rate can be increased.

As the vertical partition limit the direct contact between coconut shells, can be seen in Figure 4(a) that the partition could maintain the average temperature in 295.67°C while kiln without vertical partition went up to 321.19°C. For maximum temperature, the vertical partition was able to hold the heat in 531.33°C when the temperature inside kiln without vertical partition increased up to 650.67°C. Pyrolysis occurred in 240-350°C is the decomposition of cellulose; in 200-260 °C is the decomposition of hemicellulose and in 280-500 °C is the decomposition of lignin. This lignin decomposition resulted in higher carbon composition, up to 45.7% out of all carbon contained in a material. The heat above 500 °C will decompose the material into the other forms like synthetic gas and bio oil [7]. As the temperature went higher, there would be more material decomposed. With this vertical partition, the charcoal yield result was 23.71 % more higher than the kiln without vertical partition 18.80; as can be seen in Figure 4(b). The average calorific value of kiln with vertical partition is 7,505.33 kcal/kg, which also higher than the control, 7,458.33 kcal/kg.

![Temperature Profile on Kiln Design](image1)

![Charcoal Yield](image2)

![Caloric Value](image3)

**Figure 4.** Kiln performance data result (a) Temperature; (b) Charcoal Yield; (c) Caloric Value.
4. Conclusion

The drum kiln has 6 main components, which are pyrolysis main chamber, initial combustion chamber, air inlet, chimney, unloading part and vertical partition. Kiln with vertical partition best performance was in average temperature of 295.67 °C, average maximum temperature 531.33 °C, charcoal yield 21.67 - 26.80%, average carbonization time 78.33 minute and calorific value of 7,505.33 kcal/kg, while kiln without vertical partition best performance was in average temperature of 321.19 °C, average maximum temperature 650.67 °C, charcoal yield 17.58 - 20.67%, average carbonization time 83.33 minute and calorific value of 7,458.33 kcal/kg. Vertical partition able to limit and control kiln average and maximum temperature also increase charcoal yield.

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