Study of thermal efficiency of biomass carbonizing by direct method

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Abstract. In this study, we have designed a carbonization furnace comprising a combustion and a carbonization chamber. To know the performance of carbonization furnace, we calculated the thermal efficiency using direct method. Biomass that were used as a test material are rice husk and corn cob. We found that the highest temperature for 1.0 kg of wood fuel of combustion chamber and carbonization chamber are 648°C and 459°C, respectively. Each of the biomass has been carbonized three times at different average carbonization temperatures. It is found that the highest thermal efficiency was 2.82% and 4.43% for rice husks and corn cob, with carbonization temperature of 405.24°C and 399.80°C, respectively.

1. Introduction
Biomass is material forming from organic compound that using for energy production. The organic compound is coming from living species such as plants and animals [1]. There are two techniques for converting biomass into energy production or fuel. One of these techniques is thermochemistry. There are three thermochemical techniques, namely carbonization, pyrolysis, and gasification. Carbonization is a technique to obtain charcoal as the main product by heating biomass at 400°C-600°C in the almost or complete absence of air or oxygen. The main objective of carbonization is to increase the calorific value of charcoal [2]. The carbonization process can be carried out using a furnace having a fuel chamber as the heat generator and a carbonization chamber as the heat receiver. Generally, the heat generator is produced from hot gas or electrical heater to get high temperatures. However, the use of hot gas or electrical heater required a high energy consumption. To get a furnace with low energy consumption, it is necessary to design a simple furnace for carbonizing biomass sample. In this research, we designed simple furnace and performed carbonization of biomass sample using biomass waste as a fuel heat generator. The biomass to be carbonized was rice husks and corn cobs, while the fuel for combustion was biomass waste from woods. Here, we studied thermal efficiency of heat transfer in the simple furnace for rice husks and corn cobs samples in various temperatures.

2. Methodology
This research begins by designing a simple carbonization furnace. The simple furnace consists of two chambers that serve as a space for fuel and space for carbonization. The dimension of each chamber was 27 cm in diameters and 30 cm in height, as shown in figure 1. In the carbonization chamber, a good
heat distribution is required to make carbonization homogeniously. The cylindrical shape is chosen so that the heat spread homogeniously in all area of chamber. To reduce the heat loss, the carbonization chamber is coated on the outer wall by insulators form. For temperature control, K-type thermocouples are used. Furnace used for carbonization are designed to be simple with fuel from wood waste and small electrical energy for blowers.

![Diagram of simple furnace](image)

**Figure 1.** Design of simple furnace included (a) space of ash, (b) combustion chamber, (c) carbonization chamber and (d) chimney.

To know the temperature generated in the carbonization chamber, one kilogram of wood is burned in the combustion chamber. The amount of temperature produced is measured by the thermocouple. To determine the performance of the carbonization furnace, 250 grams of biomass each from rice husk and corncob has been carbonized on three different mean temperature variations. Based on data of mean carbonization temperature measurement, carbonization time and other parameters then calculated thermal efficiency by direct method. This method was chosen because of simple calculation involved only two parameters, namely output heat transferred to the biomass ($Q_{out}$) and the total heat of the fuel input ($Q_{in}$). The equation to find the value of thermal efficiency was shown in equation (1) [4].

$$\eta = \frac{Q_{out}}{Q_{in}} \times 100\%$$

(1)

where $\eta$ is thermal efficiency in percentage. The value of $Q_{out}$ can be obtained from equation (2).

$$Q_{out} = m_B \times c_B \times \Delta T$$

(2)

where $m_B$ is mass of biomass (kg), $c_B$ is specific heat capacity of biomass (kJ/kg°C), and $\Delta T$ is surrounding and carbonization temperature difference (°C). The value of $Q_{in}$ can be obtained from equation (3).

$$Q_{in} = Q_f + Q_r$$

(3)
where $Q_f$ is input energy from fuel (kJ), $Q_e$ is electrical energy of blower (kJ). Both values can be obtained from equation (4) and (5).

$$Q_f = m_f \times HHV_f$$  \hspace{1cm} (4)

$$Q_e = V \times I \times t_b$$  \hspace{1cm} (5)

where $m_f$ is mass of fuel (kg), $HHV_f$ is high heating value of fuel, the value of $HHV_f$ of woods is 8352.67 kJ/kg, $V$ is voltage of blower (Volt), $I$ is current of blower (Ampere), and $t_b$ is time of blower (second).

3. Result and Discussion

3.1 The test of combustion and carbonization chamber temperature without biomass

The first test of the simple furnace was measuring the temperature distribution in combustion chamber using waste biomass of 1.0 kg of firewood without biomass in carbonization chamber. To increase temperature in combustion chamber, the air supplier is needed using the blower with a voltage of 12 Volt and current of 1.2 Ampere. The result of temperature distribution in combustion chamber and carbonization chamber is shown in figure 2.

![Figure 2](image-url)

**Figure 2.** The graph of temperature distribution for every minutes in combustion chamber (△) and carbonization chamber (•).

The temperature difference in the combustion and carbonization chamber indicated the evidence of heat loss in the carbonization chamber. The heat loss is due to convection and radiation processes in the carbonization furnace. The value of temperatures in carbonization chamber was reaching to 459°C, which qualified for carbonization processes [3].

3.2 Measurement of mean biomass carbonization temperature

The process of carbonizing rice husks and corn cobs is done three times at different temperatures. The mean temperature of carbonization for rice husk and corn cob during the time of carbonization are shown in figure 3, 4 and 5, respectively.
Figure 3. Temperature of carbonization (■) and combustion chamber (●) (a) rice husk and (b) corncob at setting temperature $200^\circ$C.

Figure 4. Temperature of carbonization (■) and combustion chamber (●) (a) rice husk and (b) corncob at setting temperature $300^\circ$C.

Figure 5. Temperature of carbonization (■) and combustion chamber (●) (a) rice husk and (b) corncob at setting temperature $400^\circ$C.

The end of carbonization process is determined based on direct observation of carbonized charcoal. If all the biomass samples have turned into charcoal in a homogeneous fashion, then the carbonization process is stopped. How long it takes for the carbonization process depends on the carbonization temperature and the biomass type. The carbonization time ($t_c$), the surrounding temperature ($T_s$) before carbonization and the value of average temperature of carbonization ($\bar{T}_c$) are listed in table 1.
Based on table 1 it is seen that the greater the average temperature of carbonization, the time required during the carbonization process is smaller. It also appears that the process of carbonizing corncobs is faster than rice husks. In the process of carbonization, the average temperature increase is determined by the supply of fuel and air delivery into the combustion chamber through the blower. The air provided will improve the fuel combustion process. Thus, the heating energy generated by the combustion chamber comes from the fuel energy and electrical energy of the blower. The amount of electrical energy provided depends on the voltage, current and time of giving air \((t_b)\) during the process of carbonization takes place.

### 3.3 The thermal efficiency

The thermal efficiency and various parameters values of rice husks and corncobs calculated by equations (1) to (5) are listed in table 2. The specific calorie for rice husk and corncob is 2.772 kJ/kg°C [5] and 1.189 kJ/kg°C [6], respectively.

| Biomass   | \(\Delta T\) (°C) | \(m_f\) (gr) | \(m_B\) (gr) | \(t_b\) (sec) | \(Q_e\) (kJ) | \(Q_f\) (kJ) | \(Q_m\) (kJ) | \(Q_{out}\) (kJ) | \(\eta\) (%) |
|-----------|-----------------|--------------|--------------|---------------|--------------|-------------|-------------|----------------|------------|
| Rice husk | 188.9           | 1000         | 250          | 7200          | 103.68       | 8352.67     | 8456.35     | 131.53         | 1.56       |
|           | 270.8           | 1050         | 250          | 4500          | 64.80        | 8770.00     | 8835.10     | 187.66         | 2.12       |
| Corncob   | 381.2           | 1118         | 250          | 2100          | 35.28        | 9338.30     | 9373.57     | 264.10         | 2.82       |
|           | 188.4           | 400          | 250          | 4500          | 64.80        | 3341.10     | 3405.87     | 56.20          | 1.65       |
|           | 294.1           | 500          | 250          | 1800          | 25.92        | 4176.34     | 4202.26     | 87.57          | 2.08       |
|           | 395.8           | 300          | 250          | 1200          | 17.28        | 2497.70     | 2514.98     | 111.52         | 4.43       |

The relationship between thermal efficiency and average temperature of carbonization has been illustrated in figure 6. Based on the curve in figure 6 it shows that the greater the average temperature of carbonization, the value of the thermal efficiency increases. This shows that at high carbonization temperature will cause the absorption of energy by carbonization samples getting better. Based on the time review, the higher the carbonization temperature then the time required for the carbonization process is getting shorter. The value of thermal efficiency of rice husk is various in between 1.56% and 2.82%. The highest value of \(\eta\) for rice husk was resulted with average carbonization temperature of 405.1°C. For corncob, the value of \(\eta\) is in the range between 1.65% and 4.43% with the highest value of \(\eta\) was resulted with average carbonization temperature of 399.8°C. The value of thermal efficiency of rice husk less than corncob. It is due to the calorific value of rice husk less than corncob. The calorific value of rice husk and corncob is 14.310 kJ/kg [5] and 17.620 kJ/kg [6], respectively.
Figure 6. The curve of the thermal efficiency value as a function of the average temperature of carbonization.

4. Conclusion
Based on the results and discussion it is concluded that the designed carbonization furnace can be used for carbon biomass process with carbonization temperature reaching 459°C. Fuel used as a source of heat in the form of waste wood easily obtained. To increase the temperature in the combustion chamber is assisted with a blower with low electrical energy. It is found that the highest thermal efficiency was 2.82% and 4.43% for rice hucks and corncob with carbonization temperature of 405.24°C and 399.80°C, respectively.

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