Performance of Corncobs and Wood Charcoal Briquette as Heat Energy Sources in In-Store Dryer

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Abstract. The present study aimed to investigate the distribution of hot air drying in the In-Store Dryer (ISD) by means of corncobs and wood charcoal briquettes as heat sources. The carbonation and briquetting process are methods used to solidify corncobs biomass or wood charcoal to be used as fuel. The results showed that the heating value of wood charcoal briquettes is 7402 kJ/g from which providing air temperature ranging from 33.8 to 51.4°C, while corncobs briquettes with a heating value of 5551 kJ/g could store air with a temperature range of 27.7 - 48.8°C. Inlet air velocity of both tests reached in the range of 7.5 to 8.0 m/s while the outlet air ranges from 5.2 to 5.8 m/s. Air velocity affects the temperature and RH of the air within ISD. The performance of 5 kg wood charcoal briquettes and corncobs briquettes burning can last for 8.5-8.7 hours with an efficiency of 65% compared to pure wood charcoal. Wood charcoal briquettes could supply air with 5°C higher temperature than corncobs briquettes did, even though the overall resistance from combustion rate was not significantly different; 9.8 and 9.7 gram/minute for wood charcoal briquettes and corncobs briquettes respectively. Therefore, corncobs briquettes are potential to be used as fuels (briquettes) for ISD heat supply.

Keywords: corncobs, wood charcoal, charcoal briquettes, In-Store Dryer

1. Introduction
Energy demand in this world is always ascending, be it from small to enormous activities, such as agriculture. The instability of the price of fossil energy (petroleum), with a tendency to increase, will interfere various agricultural production processes from upstream to downstream. This condition raised awareness to find alternative energy sources from the agricultural sectors, such as food crops, horticulture, plantations, and livestock. Renewable energy from biomass is available in almost all commodities in the agricultural sector. The biomass itself consists of organic materials derived from plants or animals. Another source of energy can also come from products and cultivation waste which was processed into bioenergy. Several studies have been carried out in utilizing corncobs and rice husks to produce briquettes, such as a study by Mangkau et al.[1], a combination of 75% corncobs with 25% rice husk produced the highest calorific value of 22343 kJ/kg or 5336.536 cal/g, with the highest fixed carbon of 46.34%. Meanwhile, Hamidi et al.[2] reported the addition of 15% corncobs into the filter cake briquette produced the highest heat of 2726.588 cal/g. Nurba et al.[3], engineered and tested the performance of In-Store Dryer (ISD) for corn kernels using heat exchanger application. The result showed that the use of corncobs biomass fuel in heating furnaces is an embodiment of the concept of ‘zero waste’ agricultural management.
In-Store Dryer (ISD) is a building dryer which can be used as storage for grains (such as corn, rice, coffee, and other grains) utilizing the convective system. This dryer uses natural air as drying medium, yet natural air conditions tend to be inconstant whereas it will significantly affect the drying process and the quality of the dried grains; therefore the inlet air required temperature and RH conditioning. Nurba et al.[4] suggested RH range of inlet air between 55-70% to get an excellent drying performance. Achieving this is possible through heating the inlet air.

ISD has dimensions of 1.95 m high and 0.80 m in diameter. The entire wall is made of galvanized plate coated with a thickness of 0.002 m, which is reinforced by the framework of iron pipes. The inside of ISD building is equipped with 13 porous air conduit pipes, which serve as inlet pipes totaling 9 pipes with a diameter of 0.08 m and a height of 0.65 m from the ISD floor, while the outlet pipes amount to 4 pipes with a diameter of 0.12 m and height of 0.8 m. ISD floors shaped like plenum and equipped with material unloading holes. The floor is made of galvanized porous plates with size in accordance with ISD building size, which is 0.40 m in diameter, while the height of this plenum is 0.25 m. At the bottom of the plenum is a round hole with a diameter of 0.4 m which functions to unload the material after drying and storage process have been completed. At plenum’s lowest point, there is also an Axial Fan and Heat Exchanger to blow the drying air [3]. The ISD building is presented in Figure 1.

![Figure 1. In-Store Dryer Installation](image)

This study aims to study heat supply in ISD using corncobs briquette and wood charcoal briquette fuel so that an appropriate reference to be applied to the ISD system for grain drying will be obtained.

2. Research Methods

The tools used in this study are pyrolysis carbonation drums, hammers, sieves, stirring spatulas, pans, stoves, briquette molds, In-Store Dryer (ISD), Oven Drying, Bomb Calorimeter, Thermocouple (CA), Hybrid Recorder, Anemometer, Thermometers (wet bulb and dry bulb), Digital Scales, Measuring Bars and Notebooks. The ingredients used are corncobs, wood charcoal, water, and tapioca flour/starch.

Carbonation is a process started with inserting corncobs into the combustion tube as much as 3 kg and then burned using fire. After the fire dies out, re-enter the corncobs as much as 3 kg so then until the sample of corncobs run out, then the tube is closed using an iron cover then poured water over the tube and wrapped with wet burlap, then let it stand for one night. Furthermore, the charcoal is removed from the combustion tube, and then it is crushed using a hammer and then sifted until a fine mesh of minimum 60 mesh to be molded.

Corncob Charcoal and Wood Charcoal are mashed and mixed with 250 grams of preheated starch adhesive with a ratio of 4:1. After the mixing is done evenly, then put into a briquette molding machine. The cylindrical results are removed and weighed, then dried for 2-4 days under the sun and also in the
oven until they were dehydrated. Furthermore, proximate testing is performed to obtain the heating value, ash content, and water content.

The properties of briquettes produced will be measured, and they are water content, ash content, and calorific value, using Equations 1[5], 2[6], and 3[7].

\[
MC = \frac{W_1 - W_2}{W_1} \times 100
\]

where:
- MC: Moisture Content (% wb)
- \( W_1 \): Initial weight (gram)
- \( W_2 \): Final weight (gram)

\[
AC = \frac{m_3 - m_1}{m_2 - m_1} \times 100
\]

where:
- AC: Ash Content (%)
- \( m_1 \): Cup weight (grams)
- \( m_2 \): Cup + sample weight before heated (gram)
- \( m_3 \): Cup + sample weight after heated (gram)

\[
Q_s = m_w \cdot c_w \cdot \Delta T + Q_c - VIt
\]

where:
- \( Q_s \): Calorific Value (kJ/g)
- \( m_w \): Water Mass (g)
- \( c_w \): heat type water in the calorimeter (J/g°C or J/g K)
- \( \Delta T \): Temperature Difference (K)
- \( Q_c \): calorimeter heat capacity
- \( V \): potential difference or voltage (V)
- \( I \): electric current (A)
- \( t \): the duration of electric current flows (s)

3. Results and Discussion

3.1. Briquette Analysis

Briquetting was aimed to enhance the quality of processed material in order to be used as fuel. According to Bhattacharya et al.[8], biomass densification has several advantages, including increasing the calorific value per unit volume, improving the capability to be stored and transported, and equalizing size and quality. The quality of briquettes produced can be determined by conducting several properties evaluation such as water content, ash content, and heating value. The test results can be seen in Table 1.

| Chemical Test     | Corncobs briquette | Wood charcoal briquette |
|-------------------|--------------------|------------------------|
| Water content (%) | 3.8                | 3.4                    |
| Ash content (%)   | 8.1                | 4.1                    |
| Calorific Value (kJ/g) | 5551            | 7402                   |

Source: Data Analysis (2019)

The water content of briquettes affects heating value, the lower the water content, the better the heating value. The water content of wood charcoal briquettes and corncobs briquettes were respectively 3.4% and 3.8%; therefore, wood charcoal briquettes have less water content than corncobs briquettes. This condition happened as the water in the corncobs particles did not come out during the drying
process; another factor is moisture content from briquette adhesive. The water content of corncobs briquettes and wood charcoal briquettes has fulfilled a good briquette standard; ≤8%. This parameter will affect easiness in briquettes burning, the lower the water content, the easier the briquettes burn since the calorific value, which inversely proportional to water content, is high [9].

Ash content is the remained part after combustion; in this case, the ash analyzed is the ash from briquettes burning. One of the compositions of ash is silica, but its presence is not right on briquettes heating value. Proportionality of briquette ash content with the heating value; the smaller the ash content, the higher the heat value produced. Ash content of wood charcoal briquettes is 4.1% while in corncobs briquettes are 8.1%. From the results obtained, the ash content of wood charcoal briquettes has a smaller value compared to corncobs briquettes, and this shows that wood charcoal briquettes are better because the ash content is low so that carbon and heat value becomes increase. That is linear with the results of the study of Pane et al.[10], which states that the carbon content will increase if the ash content, water content and volatile matter content are small, the carbon content is directly aligned with heating value.

The calorific value of corncobs briquettes obtained from laboratory test is 5551 kJ/g, relatively lower than wood charcoal briquettes with a value of 7423 kJ/g. That is influenced by water content and ash content characteristics of each briquette. The heating value of briquettes is the amount of heat obtained from briquette combustion, which shows the quality of the briquettes. In addition to ash, water, and volatile substances, there is also bonded carbon content which is a fraction of C in the briquettes that also determines briquettes quality; higher bonded carbon content will give higher the caloric value, and therefore will provide better briquettes [11]. However, with the existed heating value, corncobs can be used as alternative energy because its lignin complex compounds level was ranging from 6.7 to 13.9%, hemicellulose 39.8% and cellulose 32.3-45.6% [12]. In several other reports, the level of lignin complex compounds in corncobs are 15%, cellulose 45%, and hemicellulose 35% [13]. Those requirements made corncobs suitable to be an energy source.

3.2. Burning Density and Rate
Density shows the ratio between mass and volume of charcoal briquettes. It is affected by the size and uniformity of the constituent charcoal briquettes. Table 2 shows that the density of wood charcoal briquettes was 1.16 gram / cm3, while the corncobs briquette density was 0.56 gram / cm3. The higher wood charcoal briquettes density compared to that of corncobs briquettes is because the size and uniformity of the component particles of wood charcoal briquettes are more delicate and more homogeneous. Susanto and Yanto[14] and Kurniawati et al.[15] suggested that the more uniform or homogeneous the particle size of the briquette component, the higher the density which means, the better the quality of the briquettes.

Briquette combustion rate is the time required to burn briquettes until 5 kg of ash was formed. This rate influenced by water content. The combustion rate data are presented in Table 2, showing that both briquettes types have no significant different combustion rates. Wood charcoal briquettes have a burning rate of 9.8 grams/minute, and corncobs briquettes have a burning rate of 9.7 grams/minute. This condition allows the possibility to have a cheaper fuel indicated by the condition of both briquettes after 8 hours testing, not all of their parts turned into ash.

| Material               | Density (gram/cm³) | Burn rate (gram/minute) |
|------------------------|--------------------|-------------------------|
| Wood charcoal briquettes | 1.16               | 9.8                     |
| Corncobs briquettes    | 0.56               | 9.7                     |

Source: Data Analysis (2019)

Combustion rate was also influenced by the rate of reaction between carbon and oxygen on the briquettes surface, and the diffusion rate of oxygen in the boundary layer and inside briquettes. The reaction on the briquette surface will form CO, furthermore outside the particles, CO will react further
to form CO2. The final product of combustion is ash. According to Borman and Ragland [16], the carbon contained in briquettes reacts with oxygen on the surface to form carbon monoxide.

### 3.3. Combustion of Briquettes

Embers are the result of burning briquettes where the heat lasts a long and constant; therefore, heat reduction follows the length of embers lasted. By burning the briquettes, the duration of fire flaring until it becomes embers was obtained. Corncobs briquette lasts for 36.7 minutes before it becomes embers, whereas for wood charcoal takes 25.9 minutes. The total time needed for the process of burning 5 kg of corncobs briquettes is 514.1 minutes or 8.7 hours, while 5 kg of wood charcoal briquettes required 508 minutes or 8.5 hours. From these data, it can be concluded that corncobs briquettes last longer than wood charcoal briquettes with a small difference. Combustion time of corncobs briquettes and wood charcoal briquettes are influenced by the level of small volatile substance as it has been eliminated during carbonation, whence the lower level of a volatile substance, the longer the combustion time [10].

### 3.4. Drying Temperature Distribution

In-Store Dryer chamber temperatures during combustion form an inclined and stable trend, despite inevitable fluctuations. Evaluation of corncobs briquettes showed the temperature range of 27.7-48.8°C with an average temperature of 39.0°C. While the temperature in testing using wood charcoal briquettes ranged from 33.8 - 51.4°C with an average temperature of 44.1°C. The ambient temperature during the test ranged from 28.8°C to 39.0°C, and the average temperature of 33.1°C.

The temperature was recorded every 30 minutes for 8 hours, starting at 09.00 Western Indonesian Time (WIB) until 17.00 WIB. Figure 2 displayed temperature fluctuation during the combustion of corncobs briquette and wood charcoal briquettes; the lowest temperature was 33.8°C at 09.00 WIB, and the highest temperature occurred at 12.00 WIB at 51.4°C. The heat inside the ISD chamber came from hot air produced by briquettes combustion. For corncobs briquettes, the lowest temperature occurs at 09.00 WIB, which is 31.8 °C, while the highest temperature occurs at 11:30 WIB, reaching 46.3°C.

The air temperature coming into ISD in both briquette test ranged from 5.9-11°C above the ambient temperature, which means that the performance of Heat Exchanger utilizing heat source from corncobs briquettes and wood charcoal briquettes was considered well. The temperature of drying air will affect the drying rate in ISD, the faster the evaporation occurs, the shorter the drying time required [3].

Figure 3 presents a comparative test between corncobs briquettes and wood charcoal briquettes with wood charcoal 1. The graph shows that there is a fluctuation of inlet air temperature in ISD, wood charcoal briquettes have higher temperatures with an average of 44.1°C; the temperature of wood charcoal 1 ranging from 35.0°C to 47.3°C with an average temperature of 41.2°C, while the corncobs
briquettes have an average temperature of 39°C. The difference in heat supply that occurs in ISD chamber was not only influenced by the heating value and quality of the briquettes but also affected by ambient temperature and RH as the raw material. The higher the ambient temperature, the more it will facilitate the performance of Heat Exchanger in increasing the air temperature to be blown into ISD. Continuous axial fan blows were also affecting the temperature of inlet air since the ambient air volume must have enough time to rub against the Heat Exchanger pipes in order to get higher temperatures; therefore the blowing rate will also determine the temperature of the air in ISD chamber. This condition is relevant to the statement of Wiguna and Apriani[17]; the speed of fluid flow, physical properties of the fluid, temperature differences, and the surface of heat transfer area will influence energy transfer rate in Heat Exchanger.

3.5. **Relative Humidity (RH)**

RH measurements are carried out inside the ISD chamber and ISD surrounding, to compare RH in ISD chamber and the ambient during briquette combustion. Figures 4 show the differences between ambient RH and ISD RH. RH inside ISD was lower due to the heating process of inlet air. By preheating air in Heat Exchanger using biomass furnace containing briquettes, the air temperature will increase, so that RH of air entering the ISD chamber will be lower than RH of its ambient.
Drying process of agricultural materials including grains, air humidity affects the movement of water vapor from the material to the air, when air humidity is high, the differences of water vapor pressure between inside and outside the material becomes small so that the movement of water vapor from inside the material to the outside tends to be slower, and vice versa. Nurba [18] states that the lower RH will raise more water vapor released, which fasten the drying rate.

3.6. Airflow velocity

Airflow velocity is also a determining factor in the drying process as its role as a medium in removing moisture from the material. After the water vapor moves from the material into the air, the water vapor must be immediately removed to avoid condensation. This transfer process requires airflow when air movement is fast, and the higher vapor will be carried. The air velocity in ISD during briquette testing is presented in Figures 5.

During the corncobs briquette test, airflow velocity in front of the fan (inlet) ranges from 7.5 - 8.0 m/s, while at the outlet ranges from 5.4 - 5.8 m/s. During the wood charcoal briquette test, a similar phenomenon occurred, but the value of the airflow velocity is slightly different from corncobs briquettes. The airflow velocity in front of the fan ranges between 7.5 - 7.7 m/s, while at the outlet, the airflow velocity ranges between 5.2 - 5.4 m/s. The difference of airflow velocity at the inlet and outlet occurred as the air passing through the porosity of the floor and the air duct pipes inside ISD chamber. The reduced airflow rate does not significantly affect the drying process of ISD since the rate is still at a tolerable speed between 5.2-5.8 m/s; thus it is still enabled to carry water vapor during the drying process. Massive airflow volume will simplify the drying process as the higher air volume will collect more moisture from the surface of dried material [18].

4. Conclusions and Suggestions

4.1. Conclusions

Based on obtained results, we conclude that:

1. Heat supply from wood charcoal briquettes and corncobs briquettes based on time and temperature achieved tends to fluctuate and shows average differences of 5°C.
2. The efficiency of using wood charcoal briquettes is 65% better than the use of conventional charcoal. The wood charcoal briquette used in one kiln is 5 kg compared to conventional fuel (wood charcoal) as much as 14 kg.
3. Based on research results, corncobs briquette has the potential to be used as an alternative fuel for ISD heat supply.
4.2. Suggestion

It is necessary to control the speed of air blowing into ISD in order to provide sufficient heating time of ambient air for heat exchanger before the air being blown into ISD, therefore it will reduce temperature fluctuations and equalize the heat supply.

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