DRYING PERFORMANCE OF JACKFRUIT DODOL USING RICE HUSK ENERGY ON HOUSEHOLD IN LOMBOK, INDONESIA

Ida Bagus Alit, I Gede Bawa Susana*

Department of Mechanical Engineering, Faculty of Engineering, University of Mataram, Jl. Majapahit No. 62 Mataram-Nusa Tenggara Barat 83125 Indonesia

ABSTRACT

Rice husk is a cheap fuel source and it is abundantly available in Indonesia. The heat exchanger mechanism was used in order to, the dried material was not contaminated by the combustion gases. The drying system consists of three components which include the furnace, heat exchanger pipe, and drying chamber. The heat exchanger pipe connects the furnace with the drying chamber and transfers the heat generated from rice husk burning to the drying chamber. The drying chamber was the section for drying the jackfruit dodol. It consists of 4 shelves and is equipped with an exhaust fan. The results showed capable that the dryer decreases moisture faster than conventional methods. The moisture content of jackfruit dodol reduced from 29% to 23.7% within 600 minutes and the average drying chamber efficiency was 25.3%.

Keywords: dryers, rice husks, heat exchangers, jackfruit dodol

1. INTRODUCTION

Lombok is an Indonesian island located between Bali and Sumbawa. This is a tourism area with a small industrial center for processing plantation products, especially the Jackfruit dodol, which is a traditional regional cake popular in the community. The fruit is processed into dodol to increase the sales value as well as extends its shelf life. Furthermore, the drying process is needed to preserve jackfruit dodol. The drying process is a method to preserve food ingredients to reduce spoilage and damage. Generally, this is carried out by placing the product directly under the sun or by using a dryer, in a drying room. However, both natural and artificial drying processes involve synchronous heat and mass exchange between the surrounding air and the granules. Furthermore, this process tends to reduce the moisture of a material to a minimum level thereby ensuring its safety before consumption and storage (Delgado-Plaza et al., 2020). This also needs to be supported by adequate facilities. However, in most developing countries inappropriate storage and drying facilities tend to cause post-harvest losses to the agricultural sector (Nguimdo and Noumognie, 2020). Therefore post-harvest handling is an important step adopted to maintain the quality of materials during storage (Buchori et al., 2013).

Several studies have been widely carried out on drying processes and ways of handling post-harvest losses. An instance is a gas-to-gas heat exchanger dryer designed using solid biomass to dry 2.5 kg of palm fiber (Yunus et al., 2011). The other drying process is anochy using a heat exchanger with coconut coir fuel to produce an average temperature of 41.30°C. This heat exchanger consists of pipes that are aligned and placed separately from the furnace (Susana, 2018). The biomass energy is often used in the dryer with the natural convection method and produces hot air at a temperature of 50°C (Bhuyan et al., 2016). Preliminary research compared forced convectional solar dryer with natural convection, in a designed collector area of 2 m² to dry chillies and grapes (Sushrut et al., 2015). This forced convectional solar dryer was discovered to be better in terms of drying speed and quality. Furthermore, another experimental study was carried out on solar dryers, equipped with sun tracking to dry apple slices over a temperature range of 62°C and 45°C (Das and Akpinar, 2020). The disadvantage of this process is its weather-dependent, thereby being unable to maintain continuous drying. The utilization of renewable energy such as biomass and the application of heat exchangers aforementioned is used to solve conventional agricultural and post-harvest problems. This is because conventional agriculture is dependent on weather and climate. Furthermore, the heat exchanger uses the hot air from the burning biomass in the furnace for the drying process. This device is used to transmit heat between two fluids separated by a wall and at different temperatures (Incropera et al., 2006). Biomass, which is an organic characteristic, derived from living organisms namely plants, animals, and agricultural wastes is an effective substitute for fossil energy.

Concerning biomass resources, Indonesia has great potential for this type of renewable energy, particularly rice husk as a rice waste product. Additionally, rice serves as a food source for most people with the expectation of fulfilling energy sources, carried out in rural areas through the energy conversion process such as gasification and pyrolysis. The gasification technological constitutes of 30% energy conversion used to produce 49.5 MWh of electrical energy (Pujotomo, 2017). Some of the location in Indonesia with the potential of biomass energy is West Nusa Tenggara and Lombok Island produce 533,150.80 and 269,420.20 tons of rice husks, respectively. It is estimated to produce sufficient energy to support a power capacity of 60 to 65 MW (RUED Provinsi Nusa Tenggara Barat, 2019; KPMG, 2019). Rice husk has a high heating value which is equivalent to half of the coal, namely 12.3 MJ/kg (Awulu et al., 2018). Its composition includes bulk density of relatively 90 to 150 kg/m², lignin (25% to 30%), cellulose (50%), silica (15% to 20%), and moisture (10% to 15%) (Burhenne et al., 2013; Singh, 2018). It is also a byproduct of relatively 20% of rice weight and is properly used as an energy source.

* Corresponding author. Email: gedebawa@unram.ac.id
This is due to the high composition of cellulose which tends to produce stable combustion. Biomass is used as fuel in the energy conversion process to dry rice husks at a net calorific value of 12 to 16 MJ kg\(^{-1}\) (International Finance Corporation, 2017). Furthermore, it is usually used in rural households for cooking and offering warmth to livestock. Biomass is also considered waste pollution in the environment therefore, increased logistics factors and properties are needed to make rice husks a renewable energy source (Mofijur et al., 2019). The decline in the use of firewood as fuel due to rice husks decreases deforestation and maintains sustainability (Ahiduzzaman and Sadrul Islam, 2016). Meanwhile, the utilization of rice husks in a heat exchanger furnace offers an optimal drying process.

The furnace converts the stored energy in the rice husks to thermal energy. The addition of a heat exchanger in the furnace increases the air temperature in the drying chamber (Susana et al., 2019). This study utilized black steel pipe as a heat exchanger and rice husks as fuel. In the no-load condition, the average temperature in the drying chamber was approximately 72.79°C. Meanwhile, rice husk has a combustion efficiency of 99.2% and exhibits low emissions, as well as fire stabilization (Chokphoemphun et al., 2019). This is based on the results of the test carried out on a downward furnace for drying rice (Hung et al., 2018). Furthermore, a direct test was carried out using rice husks and firewood to boil two liters of water. The result showed that the time needed to boil 1 kg of rice husk in water is 15 minutes. However, the same quality of rice husk was only boiled for 21 minutes using 1.2 kg of firewood (Yahaya and Ibrahim, 2012). Heat exchange dryers using rice husk energy are particularly suitable for household-scale drying processes and in developing rural areas. In the Philippines, the furnaces fueled by rice husks and heat exchangers with triangular tubing are used in agricultural engineering standards (Philippine National Standard, 2015). Meanwhile, those with perforated walls and the addition of heat exchanger pipes arranged in parallel optimally transfers heat into the drying chamber (Susana et al., 2019). The test results showed that it took 58 minutes to reduce the moisture content of 4 kg of corn from 19% to 12%.

The drying performance of jackfruit dodol using rice husk in Lombok is still carried out traditionally, by drying in the sun. However, according to an evaluation result based on the physical parameters, such as porosity, pore size distribution, and texture, this process deteriorates the product quality by damaging its structure (Link et al., 2017). Therefore, based on the sensitivity of certain products, such as vegetables and fruits, the sun-drying process tends to impair its sensory and nutritional properties (Ochoa-Martinez et al., 2012). Furthermore, the high production of rice husks in Lombok Island serves as an energy source for drying food in rural households, which is optimally carried out using a dryer. This is performed to enhance the standard of living in these communities.

2. MATERIALS AND METHODS

This research was carried out based on the dryer design and the optimal temperature test from previous studies (Alit et al., 2020). The optimal temperature is obtained using a 1-inch diameter heat-transmitting pipe made of stainless steel material. An 800 mm x 500 mm x 500 mm furnace, with an iron plate material of 400 mm feet is placed separately from the drying chamber. The furnace wall consists of 468 holes at a distance of 1 cm and 5 cm respectively. The design of the Jackfruit dodol dryer is as shown in Fig. 1. The arrangement of the drying chamber comprises 4 shelves made of aluminum. The drying chamber is isolated using a 3 mm thick rubber material. Furthermore, it has a dimension of 600 mm x 536 mm x 536 mm and the leg height is 400 mm. 400 mm is the support height of the drying chamber, which is the distance between the floor and the bottom of the drying chamber.

![Fig. 1 Rice husk dryer design](image1)

The drying performance of jackfruit dodol using rice husk in Lombok was carried out for 600 minutes while the moisture content was measured every 60 minutes. The data measured includes ambient, entry, inner and outer temperatures in the drying room, as well as the initial and the optimal mass of jackfruit dodol. The initial mass, \(m_0\) (kg) and dry mass, \(m_\text{d}\) (kg) is used to calculate the moisture content, \(K_m\) (%) (Henderson, 1976; Hamdani et al., 2018), as in Eq. (1). The heating procedure was carried out for 3 hours at a temperature of relatively 105 to 110°C to obtain the dry mass of dodol, \(m_\text{d}\). The mass of evaporated water, \(m_w\) (kg) is influenced by the initial mass (\(m_0\)) of the jackfruit dodol, and the mass after drying (\(m_\text{d}\)). Therefore, Eq. (2) is used to obtain the mass of evaporated water lost due to the drying process.

\[
K_m = \frac{m_0 - m_\text{d}}{m_0} \times 100\% 
\]

\[
M_w = m_t - m_p 
\]
\( m_p \) is the final mass of the material in each drying process. Obtained because each drying process will reduce the initial mass of the material due to the process of evaporation of water on the material or used to determine the mass of the material after the water has evaporated on material due to the drying process. While the dry mass (\( m_w \)) was obtained by heating using an oven to the material until there was no weight loss with the treatment carried out at a temperature of 105-110°C for 3 hours.

The heat used for drying, \( Q \) (kJ) as in Eq. (3).

\[
Q = Q_1 + Q_2
\]

\( Q_1 \) is the quantity of heat used to dry the material of water (kJ). \( Q_2 \) is the quantity of heat used to evaporate the moisture (kJ) (Hamdani et al., 2018; Çengel and Boles, 2006). \( C_{pb} \) is the quantity of specific heat applied to the jackfruit \( dodol \) (kJ/°C), \( T_a \) is the ambient temperature (°C), and \( h_{fg} \) is the latent heat of water evaporated (kJ/kg).

\[
Q_1 = m_c \cdot C_{pb} (T_b - T_a)
\]

\[
Q_2 = m_w \cdot h_{fg}
\]

\( \rho_u \) is the density of the drying air (kg/m³), while \( C_{pu} \) is the specific heat of the air (kJ/kg.°C). The inner and outer temperatures of the air are \( T_{in} \) and \( T_{out} \), respectively. Therefore, the energy transfer from air to the dried material, \( q \) (kJ) is stated as follows (Incropera et al., 2006) as in Eq. (6).

\[
q = \rho_u \cdot V_u \cdot C_{pu} (T_{in} - T_{out})
\]

The drying efficiency is as follows (Çengel and Turner, 2004) as in Eq. (7).

\[
\eta = \frac{q}{q_o} \times 100\%
\]

The ratio of Eq. (2) to the drying time, t (seconds) is the drying rate, \( \dot{m}_p \) (kg/s) (Brooker et al., 1992; Nazghelichi et al., 2010) as in Eq. (8).

\[
\dot{m}_p = \frac{m_w}{t}
\]

### 3. RESULTS AND DISCUSSION

The dried jackfruit \( dodol \) in this study is shown in Fig. 3 with initial moisture of 29% and a drying process of 600 minutes.

Fig. 4 shows the temperature distribution that occurs in the jackfruit lunckhead drying process. The higher the temperature of the hot air that comes out of the heat exchanger pipes, the higher the drying temperature. The hot air is the input temperature (\( T_{in} \)) that is used to dry the jackfruit \( dodol \) in the drying chamber. The temperature distribution shown in Fig. 4 follows the process of burning the rice husks in the furnace. At the beginning of the combustion, the water content of the rice husk was evaporated. According to Mansaray and Ghaly (1997) that the moisture content of rice husks ranged from 8.68 to 10.44%. Rice husks undergo a drying process before further heating occurs. This affects the temperature which has not increased significantly.

Rice husks are subjected to burning in the furnace starting from the bottom to the top. The combustion occurs due to the air flowing into the heat exchanger pipe and the drying room. The heat transfer from the burning of rice husk to the exchange pipe in the furnace occurs from the heat generated by the burning of rice husk outside the heat exchanger pipe which increases the surface temperature of the pipe. Then heat transfer occurs from a higher temperature heat exchanger pipe to the ambient air flowing in the pipe. Heat transfer in the drying chamber to the \( dodol \) occurs from the ambient air which initially flows into the heat exchanger pipe. This air absorbs heat from the heat exchanger pipes, then this hot air will flow into the drying chamber for the drying process. The utilization of environmental air as natural energy will reduce operating costs (Singh et al., 2019).

In the first 150 minutes, there was an increase in the temperature of the drying room (\( T_{in} \)). The average intake temperature (\( T_{in} \)) is 86.61°C which is within the range of 47.43 and 121.19°C. The average ambient temperature (\( T_a \)) is 31.07°C within the range of 28.40 and 32.51°C. The average exit temperature (\( T_{out} \)) is 49.14°C within the range of 34.23 and 61.49°C. Furthermore, the combustion process spreads upward with the increase in time until all the rice husks are burnt. On the other hand, there is a decrease in temperature when rice husks are burnt further away from the heat exchanger pipe, the temperature decreases. Generally, the temperature of the drying shelves (\( T_s \)) and the drying air (\( T_{out} \)) is based on the inner temperature (\( T_{in} \)). The temperature distribution in the drying chamber starts from the highest to the least namely shelves 1 (\( T_{s-1} \)), 2 (\( T_{s-2} \)), 3 (\( T_{s-3} \)), and 4 (\( T_{s-4} \)), respectively. The average temperature of shelf 1 (\( T_{s-1} \)) is 68.16°C, which is within the range of 39.52 and 96.81°C, while shelf 2 (\( T_{s-2} \)) is 60.76°C between 38.19 and 81.96°C. Furthermore, the average temperature of shelf 3 (\( T_{s-3} \)) is 55.48°C within the range of 35.55 and 72.84°C, while shelf 4 (\( T_{s-4} \)) is 49.28°C between 34.23 and 61.49°C.

The inner temperature of the drying chamber is uneven on each shelf due to the obstruction of hot air by the product arrangement and the lack of air passage to the overhead shelf. Also, the highest drying temperature occurred on shelf 1 because it is directly related to the heating source. This is consistent with the previous research carried out by Susana et al. (2020), which stated that the highest temperature occurred on shelf 1 in the drying chamber. Table 1 shows the data on temperature and mass change of jackfruit \( dodol \) which is measured every 60 minutes.
s helf (ms-1), 2 (ms-2), 3 (ms-3), and 4 (ms-4) were approximately 8.8%, 7.2%, had a higher temperature than others. The decrease in mass on shelves 1 process. The fastest reduction rate occurred on shelf 1 (ms-1) because it time causes a decline in mass, which was rapid at the beginning of the process. The cleansing effect is related to shelf 1 (ms-1) because it had a higher temperature than others. The decrease in mass on shelves 1 (ms-1), 2 (ms-2), 3 (ms-3), and 4 (ms-4) were approximately 8.8%, 7.2%, 5.99%, and 5.5% respectively. This decrease is based on the drying temperature distribution pattern with the least found on shelf 4 because the heat source is farther away from its position.

The period of 60 minutes is used to reduce the impact of the opening and closing processes of the Chamber because it affects the temperature distribution process, which started decreasing in the 150 minutes. This is followed by the phenomenon of burning rice husks.

Fig. 5 shows the changes in the mass of jackfruit dodol on each shelf in the drying room after 600 minutes. Jackfruit dodol with an initial mass of ± 6,000 grams (g) and moisture content of 29% was evenly distributed on each drying shelf ±1,500 g. The results showed that a longer drying time causes a decline in mass, which was rapid at the beginning of the process. The fastest reduction rate occurred on shelf 1 (ms-1) because it had a higher temperature than others. The decrease in mass on shelves 1 (ms-1), 2 (ms-2), 3 (ms-3), and 4 (ms-4) were approximately 8.8%, 7.2%, 5.99%, and 5.5% respectively. This decrease is based on the drying temperature distribution pattern with the least found on shelf 4 because the heat source is farther away from its position.

Fig. 6 compares the use of rice husk biomass and the sun to dry the moisture content of jackfruit dodol.

Fig. 7 Distribution of jackfruit dodol moisture content in the sun drying process.

Fig. 8 Comparison of sun-drying temperature (Tsd) with rice husk biomass drying temperature (Tbd).

The rice husk biomass dryer decreased in moisture content by 0.687 g/min with a chamber efficiency of 25.3%. This condition is influenced by the drying temperature. The higher the drying temperature is directly proportional to the faster drying time and vice versa. Longer operating time is affected by lower temperatures (Bevington and Robinson, 2003). Besides, this is following the research of Waheed and Komola (2019);

Table 1 Dodol mass and temperature

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Ta (°C)</th>
<th>Tin</th>
<th>Ts-1</th>
<th>Ts-2</th>
<th>Ts-3</th>
<th>Ts-4</th>
<th>Tout</th>
<th>ms-1</th>
<th>ms-2</th>
<th>ms-3</th>
<th>ms-4</th>
<th>Total mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1,487</td>
</tr>
<tr>
<td>60</td>
<td>29.94</td>
<td>86.5</td>
<td>46.19</td>
<td>53.37</td>
<td>60.64</td>
<td>67.94</td>
<td>67.94</td>
<td>67.94</td>
<td>1,465</td>
<td>1,484</td>
<td>1,496</td>
<td>1,502</td>
</tr>
<tr>
<td>120</td>
<td>32.19</td>
<td>117.0</td>
<td>57.76</td>
<td>69.26</td>
<td>77.75</td>
<td>91.44</td>
<td>91.44</td>
<td>91.44</td>
<td>1,438</td>
<td>1,465</td>
<td>1,482</td>
<td>1,489</td>
</tr>
<tr>
<td>180</td>
<td>32.22</td>
<td>118.4</td>
<td>59.46</td>
<td>70.77</td>
<td>78.52</td>
<td>94.45</td>
<td>94.45</td>
<td>94.45</td>
<td>1,409</td>
<td>1,442</td>
<td>1,459</td>
<td>1,471</td>
</tr>
<tr>
<td>240</td>
<td>32.14</td>
<td>114.3</td>
<td>56.36</td>
<td>66.91</td>
<td>74.17</td>
<td>88.88</td>
<td>88.88</td>
<td>88.88</td>
<td>1,386</td>
<td>1,426</td>
<td>1,445</td>
<td>1,459</td>
</tr>
<tr>
<td>300</td>
<td>31.88</td>
<td>102.7</td>
<td>53.35</td>
<td>60.21</td>
<td>68.36</td>
<td>77.91</td>
<td>77.91</td>
<td>77.91</td>
<td>1,376</td>
<td>1,415</td>
<td>1,436</td>
<td>1,450</td>
</tr>
<tr>
<td>360</td>
<td>31.53</td>
<td>83.25</td>
<td>50.79</td>
<td>54.74</td>
<td>60.12</td>
<td>65.23</td>
<td>65.23</td>
<td>65.23</td>
<td>1,369</td>
<td>1,411</td>
<td>1,430</td>
<td>1,442</td>
</tr>
<tr>
<td>420</td>
<td>31.09</td>
<td>73.18</td>
<td>46.78</td>
<td>51.63</td>
<td>54.40</td>
<td>58.12</td>
<td>58.12</td>
<td>58.12</td>
<td>1,363</td>
<td>1,403</td>
<td>1,423</td>
<td>1,436</td>
</tr>
<tr>
<td>480</td>
<td>30.75</td>
<td>65.52</td>
<td>45.10</td>
<td>48.54</td>
<td>50.13</td>
<td>52.41</td>
<td>52.41</td>
<td>52.41</td>
<td>1,360</td>
<td>1,397</td>
<td>1,419</td>
<td>1,431</td>
</tr>
<tr>
<td>540</td>
<td>29.98</td>
<td>55.74</td>
<td>41.19</td>
<td>42.51</td>
<td>44.30</td>
<td>45.37</td>
<td>45.37</td>
<td>45.37</td>
<td>1,358</td>
<td>1,395</td>
<td>1,415</td>
<td>1,427</td>
</tr>
<tr>
<td>600</td>
<td>29.18</td>
<td>50.16</td>
<td>36.29</td>
<td>37.49</td>
<td>39.73</td>
<td>40.48</td>
<td>40.48</td>
<td>40.48</td>
<td>1,356</td>
<td>1,393</td>
<td>1,413</td>
<td>1,424</td>
</tr>
</tbody>
</table>

Comparison of the sun and rice husk biomass used to dry the moisture content of jackfruit dodol.
Dasore et al. (2020) which states that the reduction in drying time is due to an increase in temperature. Furthermore, rice husks as waste energy exhibit good results for drying food, as well as an alternative for the development of energy-efficient dryers (Djaeni et al., 2015). One kilogram of rice husks (calorific value 15 MJ/kg) is capable of evaporates 4.5 - 5.0 kg of water vapour from paddy or shallots.

Changes in the mass of jackfruit dodol are influenced by the disparity in drying temperature. This is in line with the research carried out by Alit et al. (2020), which stated that a decrease in the mass of the dried product is based on the temperature distribution. The dried product is more hygienic because it is carried out in the drying chamber. This study is in line with Delgado-Plaza et al. (2020) that drying products using a dryer minimises animal disturbance and rainy weather conditions compared to drying in the open sun. The dryer in this study was also designed with dry food ingredients other than jackfruit dodol. Based on the results of performance tests on jackfruit dodol, it is estimated that this dryer can be used to dry other agricultural products such as coffee, bananas, turmeric, chilli, and other post-harvest products for small farmers.

Fig. 9 presents the distribution of moisture content with drying time for each shelf in the drying chamber. The fastest decrease in moisture contents occurs to shelf 1 (Ka-1) because it is closer to the drying input temperature. The farther away from the hot air source, the higher the moisture contents will be. The slowest decrease in moisture contents occurs to shelf 4 (Ka-4) because its position is farthest from the heat source.

Fig. 10 Comparison of moisture content with temperature on each shelf

Fig. 11 Comparison of mass with moisture content on each shelf

Fig. 9 Distribution of moisture content (Ka) for each shelf in the drying chamber

4. CONCLUSIONS

Rice husk is an energy-efficient fuel used for drying household products. In this research, rice husk was converted to thermal energy using the heat exchanger process, which is easy to operate and repair by the community. Based on the sample testing of 6 kg jackfruit dodol at a drying time of 600 minutes, the average drying chamber efficiency was 25.3%. The dryer tends to reduce the moisture content of dodol from 29% to 23.7%. The drying process using a biomass dryer is faster than the use of the sun in Lombok.

ACKNOWLEDGEMENTS

The authors wish to acknowledge DRPM for funding through the 2021 PTUPT research scheme with contract number 278/E4.1/AK.04.PT/2021 for the first year of research. The author also wishes to thank the Department of Mechanical Engineering, University of Mataram for facilitating the implementation of this research.

NOMENCLATURE

Greek Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_d )</td>
<td>density of the drying air ((\text{kg/m}^3))</td>
</tr>
<tr>
<td>( \eta )</td>
<td>drying efficiency (%)</td>
</tr>
</tbody>
</table>

REFERENCES


KPMG, 2019, Lombok: Prefeasibility Studies on RE Solutions.


RUED Provinsi Nusa Tenggara Barat, 2019, Potensi Limbah Perkebunan untuk Biomassa, Peraturan Daerah Provinsi Nusa Tenggara Barat, No. 3.


https://doi.org/10.24247/ijmperdoct201991


http://dx.doi.org/10.5098/hmt.12.8


https://doi.org/10.3923/jas.2011.1929.1936