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Thermal Performance of LPG Stove as Heat Source of Rotary Dryer for Drying Corn for Small Farmers

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ABSTRACT

Sunlight to dry post-harvest food materials such as corn highly depends on the weather. When it is cloudy or rainy, drying automatically stops. On the other hand, biomass dryer models such as rice husks are rather difficult to regulate the drying temperature. This study aims to create a dryer model that produces uniform temperatures and is easy for small farmers to operate. It is a rotary dryer with liquefied petroleum gas (LPG) energy. This study tested a small-scale rotary dryer based on drying time to reduce water content by up to 14%. The test used corn samples weighing 10 kg, 15 kg, and 20 kg with a water content of 18%. Testing to reduce water content to 14% is based on the Indonesian National Standard. The results showed that corn samples weighing 10 kg, 15 kg, and 20 kg required time and LPG requirements of 37 minutes and 0.092 kg, 52 minutes and 0.132 kg, and 90 minutes and 0.281 kg, respectively. The drying temperatures were 54.67°C, 55.96°C, and 57.63°C, respectively. Rotary dryers are useful for small farmers in developing areas who do not yet understand the technology. The short drying time allows this dryer machine to repeatedly dry corn.

1. INTRODUCTION

Drying is very necessary to preserve post-harvest food and extend its shelf life. Using the sun as an energy source in drying food such as corn by small farmers is an easy and cheap method. Even though it is easy and cheap, the drying method depends on the weather. Small farmers often complain about being unable to dry their products when it is cloudy or rainy and the heat changes. Based on users' participation, in this case, small farmers, the dryer model suitable for these conditions is a rotary type dryer using clean and affordable LPG (liquefied petroleum gas) energy. The advantage of using a rotary dryer is that it increases the drying rate, improves the quality of the dried product, and the drying process can be carried out continuously throughout the day (Kabeel & Abdelgaied, 2016).

Using LPG as an energy source in rotary dryers benefits small farmers because the drying process can occur continuously without depending on the weather. Apart from that, in Indonesia, the State still subsidizes LPG, specifically for small farmers, with the highest retail price being IDR 18,000-20,000/kg. LPG can be used as an alternative to replace solar energy and biomass such as firewood, rice husks, and coal. LPG in the drying process has lower energy consumption than coal. The drying productivity index is low at 0.27 dollars/quintal compared to the use of biomass, reaching 1.4 dollars/quintal, helping to meet the remaining energy needs due to low solar radiation at the beginning and end drying process (Debowski *et al*., 2021; Delgado-Plaza *et al*., 2020; Murali *et al*., 2020).

Gas is used to obtain uniform heat distribution as a substitute for sun drying (Benjamin *et al*., 2022). Sun drying takes a relatively long time because it depends on the weather. Several studies to replace sun drying include firewood, which can reduce drying time by 15%; rice husks for corn drying energy can increase the ambient temperature to

72.79°C (Lamrani & Draoui, 2020; Susana *et al*., 2019). However, sustainable use of firewood is increasingly difficult, which impacts deforestation, while rice husks provide a less uniform temperature but can be used as a substitute for firewood.

Drying corn using rice husks takes less time than drying in the sun, but the product dries less evenly (Alit *et al*., 2020). The post-harvest drying process aims to reduce the moisture content as required. The maximum moisture content of corn required and applicable in Indonesia is grouped into premium, medium I, and medium II categories, respectively 14%, 14%, and 16% (BSN, 2020). Moisture content shows the amount of water a material contains (Abadiyah *et al*., 2024). Drying corn by drying in the sun reaches three days when the weather is sunny and seven days when the weather is cloudy or rainy to reach a moisture content of 14% (Sunarti & Turang, 2017). Applying a rotary dryer is necessary to obtain a uniform temperature with evenly dried products.

Applying a rotary-type dryer with an LPG energy source provides a constant temperature during the drying process. In addition, the drying time is shorter, and the product dries uniformly so that losses in the agricultural sector can be minimized. Losses arise in the agricultural sector due to high energy consumption in inappropriate drying equipment (Nguimdo & Noumegnie, 2020; Li *et al*., 2020). For example, tobacco requires 60% drying energy consumption from production (Li *et al*., 2022). Rotary-type dryers require low maintenance costs and 15 to 30% lower specific energy consumption (Giudice *et al*., 2019). Rotary drums are widely used for mixing, cooling, heating, and drying in granular materials (Ettahi *et al*., 2022; Xie *et al*., 2018; Trojosky, 2019). The rice husk energy rotary dryer shortens the drying time for coffee beans from 16 days by drying in the sun to 3-4 days with eight working hours per day (Susana *et al*., 2023). Farmers' contributions are required in applying dryers according to their needs. Farmer participation aims to ensure that the drying process can be carried out easily and at an affordable price and does not cause new problems so that it is sustainable. A participatory approach is an effective way to redesign manual tasks, ease the physical workload, and provide more profitable work tools (Burgess-Limerick, 2018; Sormunen *et al*., 2022).

Drying is carried out for shelled corn by small farmers in rural areas as a substitute for drying directly in the sun. This is done to overcome the weakness of direct sun drying, which depends on the weather and takes a long time. Indirect drying is applied via a rotary dryer so that the product is not contaminated by smoke or LPG fuel gas. The research aims to create a dryer model that provides uniform drying temperatures and is easy for small farmers to operate.

2. MATERIALS AND METHODS

2.1. Tools and Materials

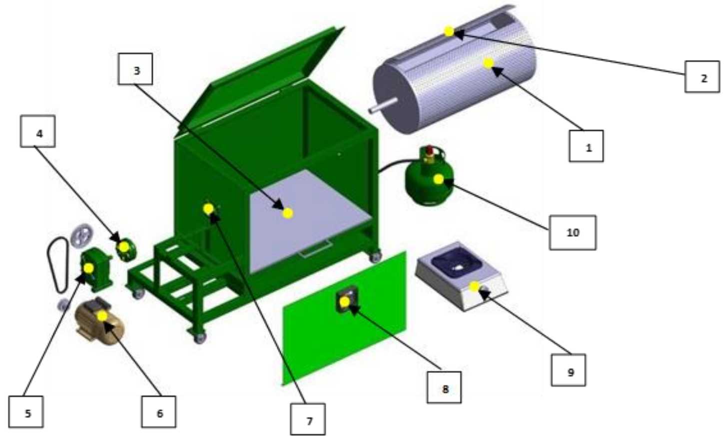
The research used materials and tools, including shelled corn, LPG, household gas stoves, K-type thermocouples, data loggers, and rotary dryers. This research used hybrid corn varieties Bima 5 and 3 kg cylinders of LPG with state subsidies for small farmers. The rotary dryer has dimensions, namely an inner cylinder diameter of 400 mm and a length of 800 mm. Materials for rotary dryers include iron plates, stainless steel plates, shaft iron, and box iron. They have exhaust fans, transmission systems, rubber insulation, gearboxes, trolly wheels, drying cylinders, and electric motors. Rotary drying machines are adapted to the needs of small farmers in rural areas to dry post-harvest food in the form of grains such as corn.

2.2. Experimental Design

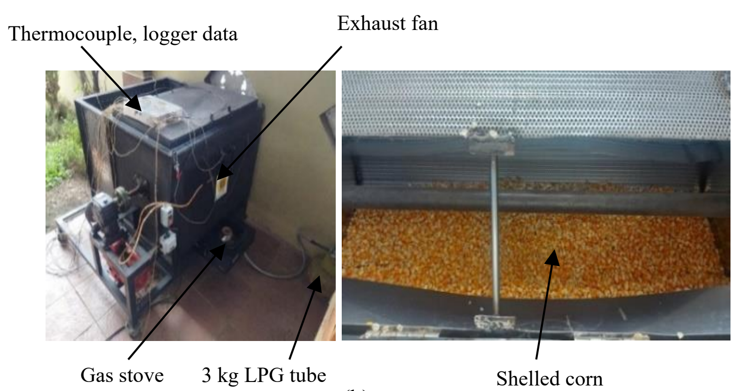
The rotary dryer used in this experiment (Figure 1) was made compact. The cylindrical drying chamber was inside a non-circular cylinder with the combustion chamber at the bottom. The combustion chamber was made flexible; its function can be replaced as a container for dry products. The non-circular cylinders outside the rotary cylinders were fixed cylinders equipped with an exhaust fan. The corn drying process was carried out in a rotary cylinder; the corn also rotated following the rotation of the rotary cylinder.

2.3. Procedures and Variables

A gear transmission with an electric drive motor assists in the rotation of the cylinder. The rotary cylinder has a lid to make entering and removing food easier. The inside of the rotating cylinder is equipped with four fins to dry food more evenly. The wall of the rotary tube is made with small holes so that the inner surface is not smooth. Circular cylinders or circular tubes create the effect of even heat transfer. Using a rough tube surface internally to develop a more effective heat exchanger and a better heat transfer rate than a smooth tube (Oyewola *et al*., 2023). Tests were carried out for variations in drying load of 10 kg, 15 kg, and 20 kg with a drying time of 90 min. The speed of the exhaust fan is constant at 2.9 m/s. The exhaust Fan works manually and is not automatically regulated, so it has a constant rotation speed. The fan speed is measured with a speed-measuring instrument (anemometer). In this study, the exhaust fan used produces a constant speed of 2.9 m/s. In addition to the initial and final mass of the corn, the initial and final assembly of the gas cylinder is also weighed. The study was carried out according to the dryer design shown in Figure 1a and sample testing as in Figure 1b. Data loggers and thermocouples are used to record temperatures installed at 8 different points, namely the drying chamber (2 points), plate (2 points), exhaust fan (2 points), and ambient temperature (2 points). Moisture content measurements during the drying process are carried out every 30 minutes to avoid the opening and closing of the drying chamber so that the temperature does not experience a large drop. The temperature is controlled by maintaining the flame on the gas stove and the speed of the exhaust fan.



(a)



(b)

Figure 1. (a) Schematic for rotary dryer run with LPG energy, and (b) Testing samples of corn grains. (1. Rotary cylinder, 2. Rotary cylinder cover, 3. Heating plate, 4. Gearbox connector, 5. Gearbox, 6. Electric motor, 7. Bearing, 8. Exhaust fan, 9. Gas stove, 10. LPG cylinder)

This research was conducted to test a rotary dryer's thermal performance in corn drying with an LPG energy source. LPG consumption was measured by weighing each sample before and after testing. Thermal performance is based on the amount of drying heat, drying rate, and drying efficiency. Data measurements included ambient temperature, bottom plate, drying chamber, exit temperature at the exhaust fan, initial or total mass, and dry mass of corn.

2.4. Data Analysis

The corn used in the drying test had an initial moisture content of 18%. Corn is obtained from small farmers in West Lombok, West Nusa Tenggara, which was previously plucked dry from the trees. The total mass of corn, m_t (kg), and the dry group of corn, m_k (kg), were used to calculate the moisture content, K_a (%) (Hemhirun & Bunyawanichakul, 2020; Nirmaan *et al*., 2020; Charmongkolpradit *et al*., 2021). To get the dry mass of corn, m_k is heated for 3 hours or until there is no weight loss at a temperature of 105-110°C.

$$K_a = \frac{m_t - m_k}{m_t} \times 100 \quad (1)$$

The amount of heat used for drying Q_a (kJ) as in Eq. (2).

$$Q_a = Q_1 + Q_2 \quad (2)$$

where Q_1 is the sensible heat of the material (kJ). Q_2 is heated to vaporize water material (kJ) (Hamdani *et al*., 2018; Çengel *et al*., 2019). Q_1 is obtained based on mass, specific heat, and temperature, as in Eq. (3).

$$Q_1 = m_k \, C_{pb} \, (T_r - T_a) \quad (3)$$

m_k is the dry mass of the material, namely corn (kg), T_r is the drying chamber temperature (°C), T_a is the ambient temperature (°C), and C_{pb} is the specific heat of the corn grains (kJ/kg.°C) based on Eq. (4) (Ince *et al*., 2008).

$$C_{pb} = 1.1444 + 0.0320 \, k_a + 0.0051 \, T_r \quad (4)$$

Q_2 is obtained based on the mass of water and the latent heat of evaporation of water as in Eq. (5) where h_{fg} is the latent heat of evaporation of water (kJ/kg), m_{ah} is the mass of water evaporated (kg), and is obtained based on Eq. (6).

$$Q_2 = m_{ah} \, h_{fg} \quad (5)$$

$$m_{ah} = m_i - m_f \quad (6)$$

m_i is the initial mass of the material (kg), and m_f is the final mass of the material (kg).

Drying rate, $\dot{m}_d$ (kg/min), calculated based on the ratio of the mass of water evaporated, m_{ah} (kg), with drying time, t (min) (Brooker *et al*., 1992; Nazghelichi *et al*., 2010).

$$\dot{m}_d = \frac{m_{ah}}{t} \quad (7)$$

Drying efficiency, η (%) based on the comparison between the amount of heat used for drying, Q_a (kJ) the amount of heat used during the drying process, Q_b (kJ) (Çengel *et al*., 2022).

$$\eta = \frac{Q_a}{Q_b} \times 100 \quad (8)$$

The amount of heat used during the drying process, Q_b (kJ), is calculated based on the mass of fuel used, m_{bb} (kg), and the calorific value of the fuel, NK_{bb} (kJ/kg), as in Eq. (9). The mass of fuel used, m_{bb} (kg), is calculated by weighing the cylinder and LPG at the beginning and end of the test; the empty cylinder is weighed first, and then the cylinder containing LPG is weighed. The difference between the end of the test and the beginning is obtained as the mass of the fuel. The calorific value of LPG (NK_{bb}) is 47120.8 kJ/kg (Dirjen Migas, 2024).

$$Q_b = m_{bb} \, NK_{bb} \quad (9)$$

3. RESULTS AND DISCUSSION

Small farmers' custom is to leave the corn dry on the trees to make it easy to pick. The dry quality standards for corn for grades one and two are 14% and 16%, respectively (Li *et al*., 2022). In this study, the moisture content of corn was calculated every 30 minutes until the testing time limit was 90 minutes. This is done to reduce the drying chamber's opening and closing so errors can be minimized. Drying corn to reach a moisture content of 14% requires a different time for each mass. At drying load of 10 kg (m-10 kg) and 15 kg (m-15 kg) take 37 and 52 min, respectively.

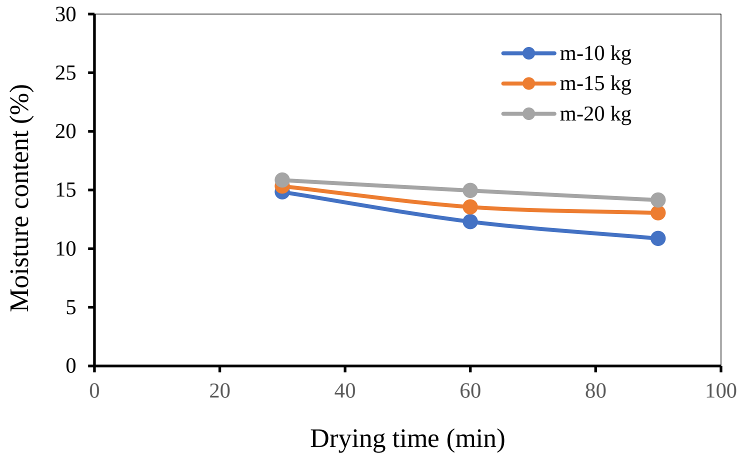


Figure 2. Effect of drying load on changes in corn moisture content

Meanwhile, at drying load of 20 kg (m-20 kg) within 90 min can reach a moisture content of 14.14%. Figure 2 shows that a drying load of 10 kg of corn experienced the fastest decrease in moisture content compared to those of 15 kg and 20 kg of corn. The moisture content of corn for a mass of 10 kg, 15 kg, and 20 kg at the 30th minute was 14.83%, 15.32%, and 15.84%, respectively. The moisture content of corn for a mass of 10 kg, 15 kg, and 20 kg at the 60th minute became 12.30%, 13.55%, and 14.95%. Meanwhile, the moisture content of corn for a mass of 10 kg, 15 kg, and 20 kg at the 90th minute became 10.86%, 13.04%, and 14.14%. The more mass of corn that is dried, the longer the drying time required to reach the desired moisture content. The drying temperature distribution is shown in Figure 3 and 4. During the test, the ambient temperature (T_a) was almost the same for drying corn with masses of 10 kg, 15 kg, and 20 kg. The average ambient temperatures are 29.12°C, 29.09°C, and 29.49°C. Measurement of the drying chamber temperature (T_r) is carried out based on the moisture content measurement settings, which is carried out every 30 min. Meanwhile, the mass of 20 kg of corn is 52.86; 57.10; and 57.63 °C respectively (Figure 4a).

Using LPG as an energy source in the drying process provides temperature stability in the drying chamber. However, this study found that the drying temperature decreased at the beginning of the test. This is due to the influence of corn mass when it is put into the rotary drying chamber. Heat transfer occurs from the drying chamber to the environment, which causes the temperature in the drying chamber to decrease. The hot air inside the drying room comes out when the drying chamber is opened. After the drying chamber was closed again, the temperature of drying

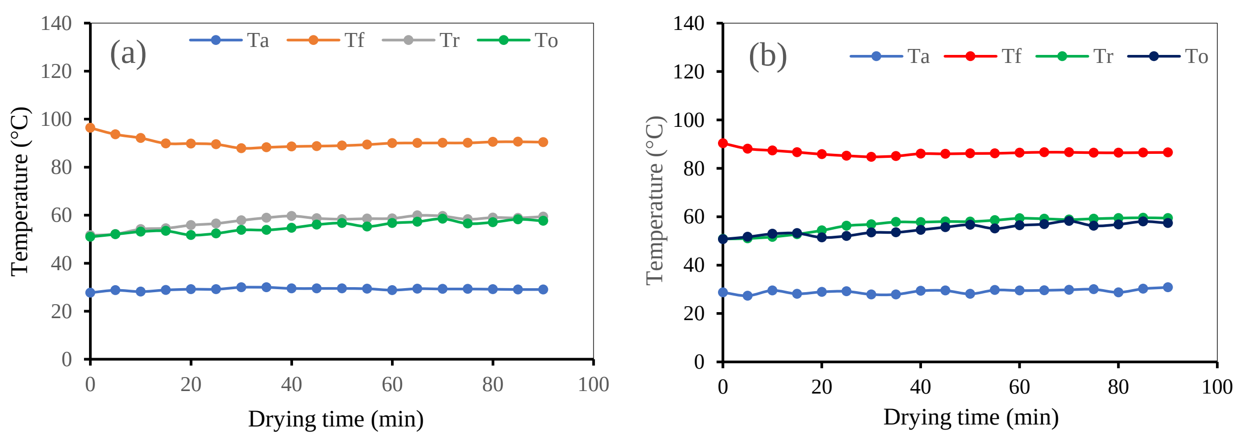


Figure 3. Distribution of ambient temperature (T_a), plate (T_f), drying chamber (T_r), and outlet from drying chamber (T_o) for corn mass (a) 10 kg, (b) 15 kg (a) 10 kg, (b) 15 kg

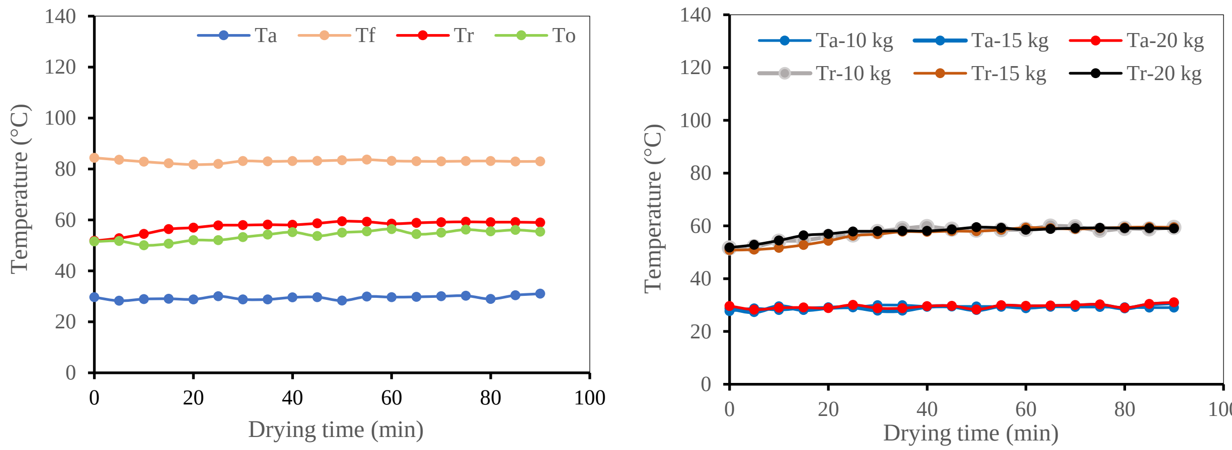


Figure 4. Drying temperature distribution for the mass of corn (a) 20 kg, (b) comparison of ambient temperature with rotary drying chamber

chamber began to increase. The time required to reach 14% water content in each sample is different. For corn masses of 10 kg, 15 kg, and 20 kg, the drying time is 37 min, 52 min, and 90 min, respectively. It was found that the greater the mass of corn used, the higher the temperature needed to dry the material to reach the required moisture content, in this case, 14%.

Generally, the LPG-fired rotary dryer used in this test can dry up to 20 kg of food. As shown in Figure 4b, LPG fuel can maintain a stable drying temperature for the rotary dryer. This is better than using biomass, as shown in the study of Alit *et al*. (2020), who used rice husks to dry corn. However, the drying temperature became unstable because the combustion of rice husks in the furnace was difficult to control. The drying process can be far more optimal than drying in the sun, which relies on ambient temperature. This can be seen from the average ambient temperature of 29.09°C to 29.49°C, while rotary drying can provide an average drying temperature of 52.86°C to 57.63°C. To obtain a shorter drying time, increase the drying temperature. The increased temperature decreases the drying time (Waheed & Komolafe, 2019; Dasore *et al*., 2020). This condition affects the drying rate that occurs in the dried material. With temperature conditions that tend to be stable, the drying rate is affected by the mass of the material being dried, as shown in Figure 5. The drying rate in the mass variations of 10 kg, 15 kg, and 20 kg corn, showing a downward trend. This follows the movement of the moisture content; the longer the material is dried, the more the moisture content decreases, so the drying rate decreases. Until the end of the test, namely at 90 min, it was seen that the drying rate was the fastest for 20 kg corn mass compared to 10 kg and 15 kg. The decrease in drying rate is directly proportional to the

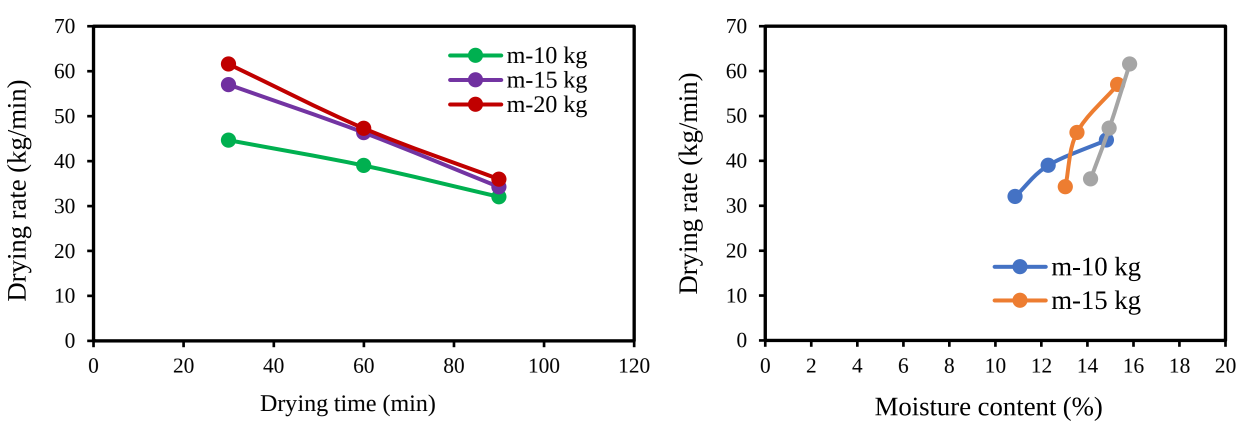


Figure 5. (a) Effect of load and drying duration on drying rate, (b) effect of drying load and material moisture content on drying rate

reduced moisture content, as shown in Figure 5b. The highest drying rate occurred at 20 kg corn mass. The moisture content in the mass of 20 kg corn is higher than 10 kg and 15 kg, impacting a higher drying rate. The higher moisture content provides a relatively high drying rate (Lakshmi *et al*., 2019). In the 30-minute test, the 20 kg corn mass experienced the highest drying rate, namely 61.56 kg/min or 1.026 kg/hour. The drying rate for a mass of 15 kg is 57 kg/min or 0.950 kg/hour. Meanwhile, a mass of 10 kg is 44.64 kg/min or 0.744 kg/hour. At the end of the test, namely the 90th min, the drying rate that occurred for the corn mass of 20 kg, 15 kg, and 10 kg was 35.96 kg/min or 0.599 kg/hour, respectively 34.24 kg/min or 0.571 kg/hour, and 32.04 kg/min or 0.534 kg/hour. The smaller corn mass has a lower moisture content, so the drying rate will be lower, and the drying time will be faster.

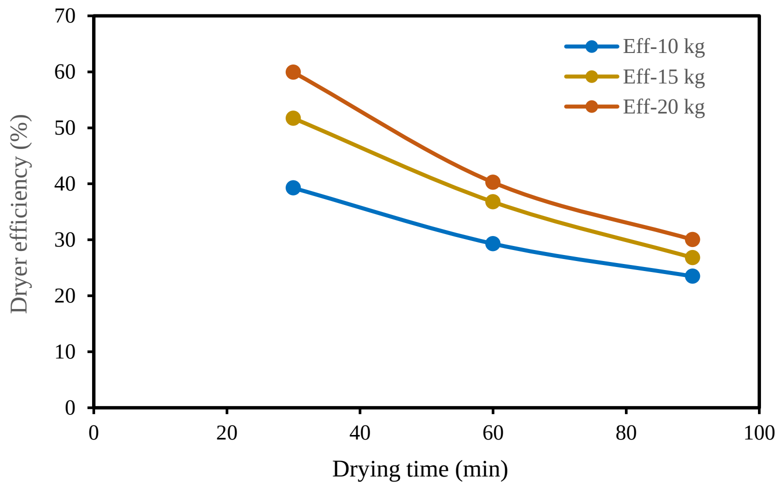


Figure 6. The effect of load and drying duration on dryer efficiency (Presents the relationship between drying efficiency, drying time, and corn moisture content)

The drying rate decreases with decreasing corn moisture content. Increasing the drying rate affects the loss of free moisture content due to sensible heat transfer to the corn sample. Increasing the drying temperature causes the drying rate to increase. High drying rates occur when the moisture content of the material is still high. The moisture content decreases, followed by a decrease in the drying rate. The drying rate is relatively higher at higher moisture content. The greater the mass, the higher the evaporated moisture content, thus resulting in slower drying compared to smaller material masses.

Drying efficiency is calculated every 30 minutes according to the moisture content measurement. For all variations of corn mass, drying efficiency is highest at the beginning of the drying process. This is due to the high moisture content in corn. This result is in line with the research of Djaeni *et al*. (2019), who stated that the initial efficiency of the drying process was very high as the energy impact of the dryer absorbed by the product was still high.

In addition, during the drying process, there is a decrease in moisture content so that the energy absorbed by the outcome decreases. A corn mass of 20 kg (Eff-20 kg) has the highest drying efficiency compared to 10 kg (Eff-10 kg) and 15 kg (Eff-15 kg). This is due to the higher moisture content in the larger mass of corn. At 30 min, the efficiency of drying sequentially from the enormous corn mass was 59.91%, 51.70%, and 39.25%. At 60 minutes, it was 40.25%, 36.77%, and 29.29%. At 90 minutes, it was 30.02%, 26.80%, and 23.47%. The greater the mass of corn, the higher the drying efficiency that occurs, and vice versa. Drying efficiency decreases following the decrease in corn moisture content and occurs in all mass variations. The decreased moisture content (K_a) in corn causes a decrease in drying efficiency. It was found that the efficiency decreased during the drying process for all mass variations. Evaporation in corn impacts the smaller moisture content, which causes more heat to be used for wasted drying.

The use of LPG as an energy source for rotary dryers is very affordable because it still receives subsidies from the state. This applies to small farmers in Indonesia, who have the highest retail price of IDR 19,000/kg. This research shows that LPG consumption for drying corn until it reaches a moisture content of 14% according to the requirements of the Indonesian National Standard for samples of 10 kg, 15 kg, and 20 kg is 0.092 kg, 0.132 kg, and 0.281 kg, respectively. So, the costs incurred are IDR 1748, IDR 2508, and IDR 5339. The calculation results are based on LPG consumption per kilogram of corn, which differs in each sample mass. For a 10 kg sample, LPG consumption and costs are 0.0092 kg LPG/kg corn and IDR 174,8/kg corn. For a 15 kg sample, it is 0.0088 kg LPG/kg corn and IDR 167.2/kg corn. For a 20 kg sample, it is 0.01405 kg LPG/kg corn and IDR. 266.95/kg corn. LPG consumption and costs for the 20 kg corn sample are the highest. This is due to the time required to reach a water content of 14% longer than for the 10 kg and 15 kg samples. Further research is needed regarding this consumption. Applying rotary drying machines using LPG energy sources is very profitable for small farmers based on these conditions.

4. CONCLUSION

A rotary dryer fueled by LPG (Liquefied petroleum gas) using a household gas stove is used to dry corn kernels as an alternative to replacing sun drying or firewood. The use of a rotary-LPG dryer in this study was able to increase the ambient temperature by 95.14% -97.11%. This is to achieve a water content of 14%, according to the Indonesian National Standard. The average drying temperature for corn masses of 10 kg, 15 kg, and 20 kg were 54.67°C, 55.96°C, and 57.63°C, respectively. The time required to achieve it was 37 minutes and 52 minutes for the masses of 10 kg and 15 kg, respectively, while the mass of 20 kg took 90 minutes. Until the end of the test, namely at the 90th minute, the fastest drying rate occurred for the mass of 10 kg corn compared to 15 kg and 20 kg. The decrease in drying rate is directly proportional to the decrease in moisture content. The highest cost occurred in the 20 kg sample test, namely the drying process within 90 minutes to reduce the water content by 14.14%, which requires consumption of 0.01405 kg LPG/kg corn and a cost of IDR 266.95/kg corn. For a mass of 10 kg, it takes 37 minutes with LPG consumption and a cost of 0.0092 kg LPG/kg corn and IDR 174.8/kg corn grains. For a mass of 15 kg, it takes 52 minutes with a consumption of 0.0088 kg LPG/kg corn and IDR 167.2/kg corn. Rotary dryers will be more efficient for drying loads of 15 kg of corn based on the fuel consumption. In addition, the reduction in corn water content affects drying efficiency, which decreases. Evaporation that occurs in corn impacts the decreasing water content, and this condition causes more heat used for drying to be wasted. This rotary dryer is useful for small farmers who have household-scale corn production. In addition, drying can be carried out at any time because it does not depend on the weather. From the condition of the workers, farmers in the drying process are not exposed to the hot sun, which can be categorized as an additional workload that affects the level of farmer fatigue.

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