Tray Dryer's Performance in the Drying of Banana Slices Using LPG and Wood Stove

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Abstract: An evaluation was carried out on a simple tray dryer of banana slices in the "sale pisang" production. The dryer is designed to use gas fuel and a wood-burning stove as a source of energy. The dryer's performance is analyzed to evaluate its ability to dry the product efficiently and effectively to prevent excessive heat use. The research aims to analyze the temperature distribution in the drying chamber, the profile of the product's moisture content, the drying rate on each shelf, as well as the efficiency of dryers using gas fuel and wood-burning stoves. At an air speed of 0.0176 m^3/s, the drying chamber reaches a maximum temperature of 76.2 °C using gas and 66.23 °C using a wood stove. The use of Liquid Petroleum Gas (LPG) gives an average room temperature of 73.46 °C, while the furnace gives a less stable pattern with an average temperature of 63.02 °C. Drying using LPG occurs more quickly with a constant drying rate and a falling rate period of 0.8262%/hour and 0.01504%/hour, higher than using wood fuel which is 0.5482%/hour and 0.0098 %/hour. Within 400 minutes, the product's moisture content reached 24.64% using LPG and 36.762 using the furnace. The efficiency for heating the drying air is 28.51% and the drying process efficiency is 27% using 8.6 kilograms of LPG as fuel. Meanwhile, using a furnace energy source, the dryer provides a heating efficiency of 15.9% and a drying efficiency of 7.37% with a fuel consumption of 34.12 kg of wood.

Keywords: banana; drying performance; LPG; tray dryer; wood burner

INTRODUCTION

Background

A simple tray dryer was built to dry banana slices in the production of "Sale Pisang". "Sale Pisang" is a kind of diversification in banana consumption, as a tropical fruit that has a lot of essential elements for diet i.e. fat, natural sugars, protein, potassium, and vitamin A, B complex, and C (Hapsari & Lestari, 2016). The diversification is also conducted to extend its shelf life as a climacteric fruit and increase its value. The banana was sliced, pressed, and dried from a moisture content of 18 to 20 % before producing "Sale Pisang" (Suryani *et al.*, 2016). Traditionally, the drying is conducted by direct sun drying (Kushwah *et al.*, 2023). Different from the previous research, in this research the dryer was designed more simply with a small capacity according to the production capacity of "Java Sale Banana" and used materials available locally in UMKM.

To support the production of "Sale Pisang", a tray dryer has been developed to change the traditional dryer using solar energy. Although offering cheaper drying, solar drying has some disadvantages in its dependence on unpredictable weather, a large area, a long-term drying process, and quality reduction caused by its contamination and spoilage (Udomkun *et al.*, 2020). A tray dryer is expected to conduct the drying at a more stable temperature and accelerate the drying process. It is also required to keep the flavor during the drying process and support good conditions for the formation of aroma as an effect of temperature in drying.

As an important process in food production, the totality of the drying process determines the quality and quantity of dry products produced. This is supported by the significant use of energy for dryers which can reach 60% of consumption (Prakash & Kumar, 2017).

A tray dryer consisting of 6 trays, had been designed simply to help small industries. As applied in the usual dryer, the drying air is blown using a blower to circulate the energy to accommodate the drying process. It is also applied as a medium to carry the evaporated vapor during drying (Chitsuthipakorn, 2022). Before entering the drying chamber, the air was heated when it was blown within the heating room above the furnace. They should accommodate heat and mass transfer processes causing the removal of the water content of the product by evaporation. Hot air drying was a method that was used widely to dry products rapidly and create products to be more uniform. The dryer supporting "Sale Pisang" production should be evaluated before being applied to support the drying of banana slices.

The dryer should operate a good movement of drying air to deliver the energy evenly, curb their flavor, and avoid caramelization. Good circulation is also required to move the vapor from the evaporation during drying exit the drying chamber to avoid the accumulation of humidity that inhibits the sustainability of drying. The blower blew the air into the drying chamber through the heat exchanger. The air was guided to pass through the banana slices spread in each tray. The heat circulation supported by the forced convection can be used to improve drying efficiency (Silva *et al.*, 2021). The drying temperature and humidity affected by the circulation are parameters in a drying acceleration besides the thermophysical properties of product (Majdi & Esfahani, 2018).

The drying air was exhausted from the drying chamber by the difference in air pressure between the bottom and the top of the dryer. This dryer was constructed simply from available material in the surroundings applying bamboo slices as the walls and wood as the frame. The drying air was heated in the indirect heat exchanger using a burner stove with Liquid Petroleum Gas (LPG) and wood as fuel material. Fuel selection is based on the type of fuel available for production operations in the location. Energy supply adapted to available energy resources in "Java Sale Pisang" as small industries where the dryer would be applied.

Before applying, the performance of the dryer should be evaluated. The evaluation should describe the temperature distribution in each tray to support the drying process uniformly. It also should analyze the drying rate based on the decrease in the moisture content of the product during the drying. The energy consumption and the efficiency of energy in heating the drying air and drying the product were also an important parameter to show the drying performance. Applying a mathematical model during the drying, the final moisture content of banana slices could be set by determining the time of drying.

Objective

This research was purposed to analyze the temperature distribution, the change of their moisture content, and the drying rate in each tray during drying. This research also analyzed the fuel consumption of dryers, and the energy efficiency to heat the drying air and to dry the product.

RESEARCH METHODS

A performance evaluation was conducted on a simple tray dryer in the drying of banana slices from *Musa paradisiacal Linn var. uter* in this research. The dryer in Figure 1 was applied in small Industry Java "Sale Pisang" Mangunan, Imogiri, Yogyakarta. The dryer was designed from local materials in the surrounding industries. It has a tunnel for heating the drying air completed by 2 blowers. The structure is crafted from mahogany wood, while the walls are constructed using woven bamboo. The chamber for the drying air duct is fabricated from stainless steel.

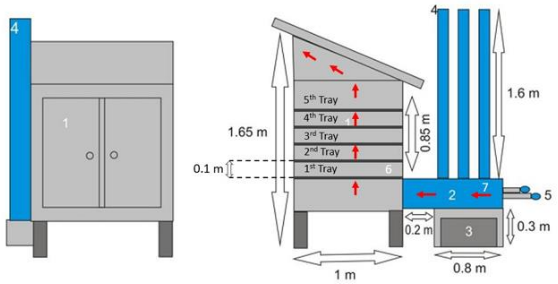
In the performance evaluation, the bananas were peeled, sliced, and pressed in the thickness of 3 mm, and then spread into thin layers in 5 trays in the drying chamber. The drying air was set at 0.0176 m^3/s as the minimum capability of the blower supply. The drying was conducted using a Mahogany's wood as a source of energy in the burner and an LPG for comparison.

During the drying, the temperature of the plenum and each level tray in the chamber were measured every 40 minutes using thermocouple. The moisture content of banana slices was calculated every 40 minutes by applying a thermogravimetry method to evaluate the drying mechanism, the drying rate, the amount of water evaporated, and the system efficiency. The decrease in the product moisture content was interpreted in a constant rate drying period (Equation 1) and a falling rate drying period (Equation 2) (Susanti *et al*., 2016). The falling rate period was approached using the theoretical thin-layer model (Tunckal, 2020; Wang *et al*., 2007).

$$\frac{dM}{dt} = -k \text{ ....(1)}$$

$$MR = \frac{(M - Me)}{(Mo - Me)} = \exp(-kt) \text{............(2)}$$

The MR value is the moisture ratio; while the values of Mo, Mt; and Me were the initial moisture content, moisture content during drying, and equilibrium moisture content in dry basis (kg H_2O/kg dry matter. minutes) (Djaeni *et al*., 2018; Franco *et al*., 2015; Khodabakhshi *et al*., 2015; Susanti *et al*., 2021).



1. Drying chamber
2. Tunnel
3. Burner
4. Chimney
5. Blower
6. Tray
7. Air Flow

Figure 1. Schematic construction of simple tray dryer

The value of drying efficiency was described as a ratio of heat energy used for moisture content evaporation to the energy consumed in Equation 3 (Khodabakhshi *et al*., 2015). The energy for evaporation consisted of sensible energy and latent energy, whether energy consumed depended on the rate of fuel combustion (Beigi, 2016).

$$\eta = \frac{Qsensible + Qlatent}{m_{bb}\, x\, f}\, x\ 100\% \text{...............(3)}$$

The efficiency for heating the drying air in the dryer was calculated from the ratio of the energy to increase the drying air enthalpy and energy consumption from the burner, shown in equation 4 (Suherman *et al*., 2020).

$$\eta = \frac{Q\, x\, \rho\, x\, (h_2 - h_1)}{\frac{m_{bb}}{t} x\, f}\, x\ 100\% \text{...................(4)}$$

The value of Q is the rate of drying air (m^3/s); ρ is the density of drying air (kg/m^3); h_1 is the enthalpy of ambient air (kJ/kg); h_2 = the enthalpy of the heated air (kJ/kg); f is the caloric value of fuel (kJ/kg); t is the drying time (hour).

RESULTS AND DISCUSSION

The Temperature Distribution During the Drying

To support its function in drying, the drying air was heated indirectly. The energy was supplied from the burner in the stove using LPG and wood as fuel. The temperature of drying air blown from the surroundings increases from the ambient temperature before entering the drying chamber as an accumulation of indirect heating during a pass within the tunnel above the burner. Indirect heating is designed to separate the air from the ash of fuel. The fuel and their ash were exhausted through 2 chimneys set on the backside of the stove to blow them on the top side of the dryer. They were exhausted by the difference in air pressure between the room burner and the top side of the chimney.

The profile of temperature in the plenum chamber is illustrated in Figure 2. From the ambient temperature (26.3 °C), the drying air increased gradually and raised the maximum temperature to 76.2 °C using LPG as the fuel. The temperature of drying air in the plenum chamber increase faster using LPG than a wood stove, The maximum temperature using a wood stove was 66.23 °C. Its profile indicated the energy accumulation in the drying air when they were blown at the velocity of 0.176 m^3/s. The temperature of the plenum chamber using a wood burner was relatively lower than LPG. As depicted in Figure 2, the temperature using wood combustion is stretched between 26.3 to 66.23°C. The energy supply using wood depended on the supply of wood during burner.

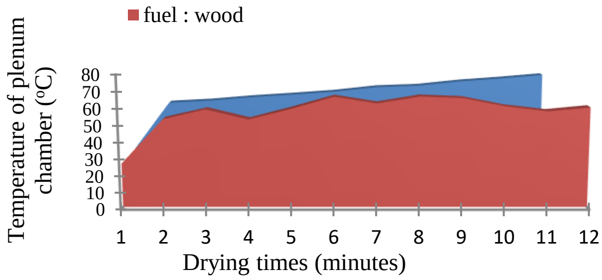


Figure 2. Temperature of plenum chamber using wood and LPG

The difference between the plenum chamber from the two types of burners as described in Figure 2 affected the difference in the temperature profile of drying air distributed in each level tray in the dryer, illustrated in Figure 3 and Figure 4. The temperature of drying air in each tray using LPG was relatively higher than wood burner.

The temperature decreased gradually from the bottom of the plenum while the increase of the tray position increased. It showed a decrease in its energy because of the increase of accumulation of absorbed energy by banana slices as sensible and latent heat to evaporate the vapor from the slices. Using LPG, the average temperature in the drying chamber using LPG increased gradually, reaching 73.46 °C, whether using a wood stove had an unstable pattern reaching a maximum value of 63.02 °C. The profile of temperature is still an important aspect that affects some changes in a product quality such as structure, chemical modification etc (Jaya *et al*., 2022).

When the energy was supplied by the wood burner, the distribution of temperature in each tray dryer was lower than LPG. The maximum temperature was 65.1 °C in 1st tray using a wood burner while 75.7 °C using an LPG burner. The average temperature in the drying chamber is illustrated in Figure 5. However, the lower temperature was believed to keep some heat-sensitive products safer for their flavor and nutrition. The sensitive compounds are fat, vitamin C, and reducing sugars (Takougnadi & Boroze, 2020). If the temperature is too high and the humidity too low, the food case hardening on the surface might happen. Drying under 70 °C could avoid case hardening. The drying condition was required to remove moisture fastest at the lowest temperatures and affect their flavor, texture, and color (Petikirige *et al.*, 2022).

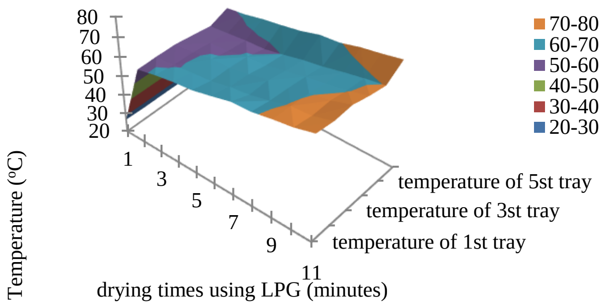


Figure 3. Temperature in chamber during drying using LPG

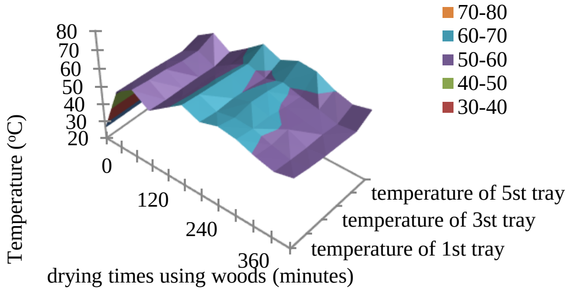


Figure 4. Temperature of plenum chamber during drying using woods

The temperature of the drying process affected drying time. A higher temperature in drying caused the drying process faster than a lower temperature but too high temperature caused deterioration of physical parameters and some nutrition of products. Based on the Figure 3 and 4, the optimum drying is recommended at the temperature of 65-75°C during 400 minutes. It is suitable with the optimum temperature in drying banana from a reference, from 60 - 70 °C (Leite *et al.*, 2007).

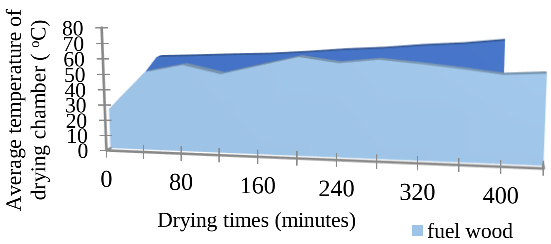


Figure 5. The average temperature of the chamber using wood and LPG

The change of moisture content during drying

The banana slice's drying was conducted until there was no significant decrease in their moisture content with an increase in the drying time. The final moisture content was lower than the target drying in "Java Sale Pisang", which is maximum at 24,04% of moisture content. The value was enough to be fried in starch suspension in production "Sale Pisang". The final moisture content was stretched between 17.88% and 24.4% suitable with the standard operating procedure in the industry of "Sale Pisang" before frying in the dough, which they reached when using direct solar drying (24.4%). The maximum value based on SNI 01-4319-1996 was 40%.

During 440 minutes of drying, the moisture content of banana slices decreased from 68.41 % to 20.08 % wet basis (Figure 7) or 216.58 % to 25.43 % dry basis (Figure 6) when the tray dryer was operated using a wood burner as a source of energy respectively. Using LPG as a source of energy, tray dryer dried banana slices from 71.55 % to 19.744 % wet basis (Figure 7) or 251.55 % to 24.64 % (Figure 6) dry basis. The final moisture content was closed to the final moisture content using solar dryer (18.6%) (El-wahhab *et al.*, 2023). Using the wood burner, the decrease of moisture content was slower than using LPG. So, drying banana slices using a wood stove needs a drying time of 440 minutes, 40 minutes longer than LPG. It showed that moisture loss from the product was directly proportional to temperature increase.

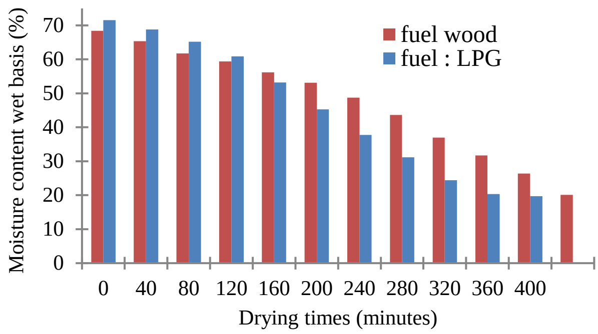


Figure 6. The average moisture content wet basis during drying

The profile on the drying in each tray was described in Figure 8 and Figure 9, using LPG and wood burner respectively. Each tray had a specific rate in drying. The rate of moisture content reduction increased while the increase of temperature and the decrease of absolute pressure of drying air in each tray (Swasdisevi *et al.*, 2007).

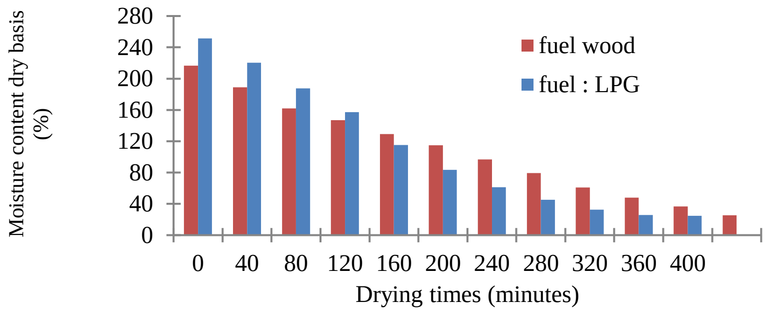


Figure 7. The average moisture content dry basis during the drying

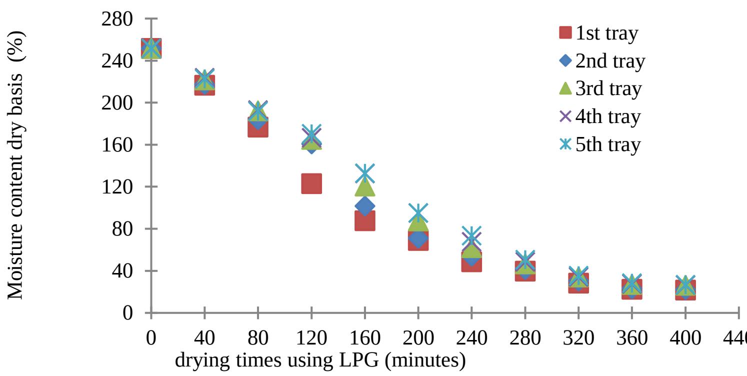


Figure 8. Moisture content of product (%) using LPG for burner

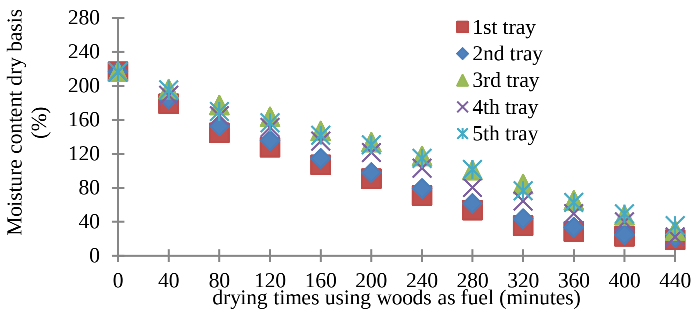


Figure 9. Moisture content of product (%) using wood burner

The drying kinetics

In this research, the drying phenomena are also evaluated from the change in moisture content. The analysis was interpreted using a thin-layer equation approach, which describes the drying mechanism. Using a thin layer approach, the product is described to be fully exposed to drying air under constant conditions of temperature and humidity (Amer *et al*., 2023).

The phenomena during the drying of banana slice is described as consisting of 2 periods, a constant rate period and then a falling rate period. At the beginning stage, the moisture content dropped rapidly and then decreased gradually till it reached equilibrium moisture content (Khawas *et al*., 2014). The decrease of moisture content was faster in the beginning showing the evaporation of free water content from the surface. It was initiated by the difference in vapor pressure between internal and drying air. When the water on the banana surface evaporated suddenly, hardening occurred at the surface, assisting in maintaining the shape of the banana (Swasdisevi *et al*., 2007). The lower temperature gave more good qualities (high lightness, low yellowness, low shrinkage, and low hardness) (Swasdisevi *et al*., 2007). During the falling rate period, the drying rate decreased continuously while the decreasing of moisture content and drying time (Khawas *et al*., 2014).

The constant value of the drying rate was calculated using Eq. 1 and Eq. 2. The constant value of the drying rate in each period was displayed in Figure 9.A. for the constant rate period and Figure 9.B. for the falling rate period.

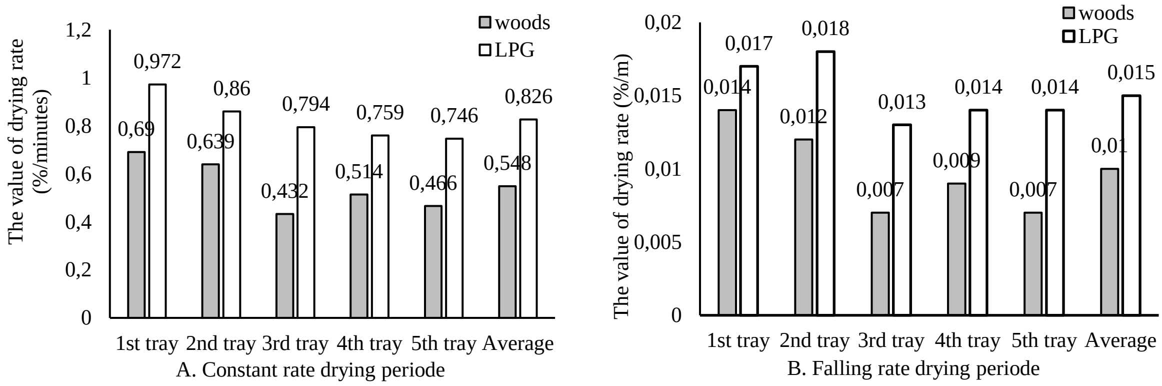


Figure 10. The constant value of each drying rate period using wood burner and LPG

When the dryer used LPG as its fuel, the average drying rate during the constant drying rate period and falling rate period (0.8262 %/hour and 0.01504 %/ hour) were higher than using wood as fuel (0.5482 % / hour and 0.0098 %/ hour). The average value of the drying rate in each period was used to predict the moisture content of banana slices during drying, as illustrated in Figure 11. Based on the suitability between the observed values and the predicted values, the model can be applied to predict the process and describe the drying process on each shelf and the fuel used. The model also describes the differences in mass transfer kinetics under different conditions (Pravitha *et al.*, 2022) which are influenced by the shelf position of the heating source and different types of fuel consumption.

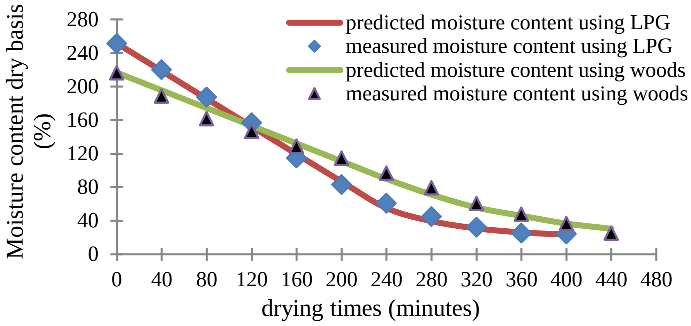


Figure 11. The predicted moisture content of product (%) using LPG and wood burner.

The energy efficiency of the Tray dryer

The source of energy used in this dryer was distributed in the system supporting the drying process. The ratio of the amount of energy used for supporting the drying and the supplied energy from the burner showed the efficiency of the system in directing energy. In this research, the energy efficiency using LPG and the wood burner was compared for their capacity to heat the drying air as a medium to deliver the energy in each tray's drying process. The energy from the stove was carried by the drying air when they flew in a tunnel above the furnace to be heated indirectly (Hamdani *et al.*, 2018). Woods used to be an alternative source of energy because they were available and abundant in the surrounding industries. The biomass derived from forestry residues, waste products, and agricultural wastes could provide an energy source.

The supplied energy from the burner was used to heat the drying air and then the energy of the drying air supported the drying process. During the drying, the wood consumption for fuel was 34.12 kg wood for 440 minutes, while the consumption of LPG was 8.6 kg for 400 minutes. The energy efficiency of the tray dryer calculated by Eq. 3 and Eq. 4 has been illustrated in Figure 12. The energy efficiency for the heating drying was higher if the dryer operated using LPG than the wood burner. The value described the amount of energy to increase the enthalpy of the drying air from the ambient temperature before entering the drying chamber. The LPG also gave a higher energy efficiency for drying the product. The efficiency described the ratio of energy for increasing the sensible heat of product and evaporating the water content of banana to the amount of energy from burner.

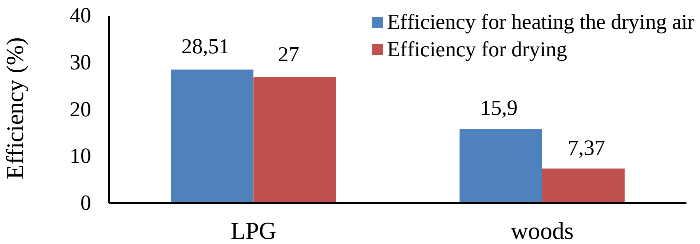


Figure 12. The energy efficiency for heating the drying air and drying process

Energy from LPG created drying conditions to dry "sale" faster and produce a lower moisture content than energy from wood-burning. Using 8.6 kilograms of LPG for 400 minutes, efficiency of dryer was 28.51 % to heat drying air and 27 % to support drying process. While using 34.12 kilograms during 440 minutes of wood, efficiency of dryer was 0.5482 % to heat drying air and 0.0098 % to support drying process.

CONCLUSION

A performance evaluation had been conducted on a tray dryer before being applied in "Java Sale Pisang" in Mangunan, Bantul, a small industry that needs to dry banana slices to produce "Sale Pisang". The dryer was designed simply using 2 blowers, and other materials available surrounding the industry, complete with a burner. The dryer performance was evaluated as a source of energy from LPG and a wood burner to heat the drying air indirectly within the tunnel above the stove. The performance of the tray dryer using LPG was better than that using a wood stove, from the temperature distribution in each the chamber of dryer and the drying constant rate of each period drying. For better performance, the LPG resulted in the dryer in a higher efficiency.

SUGGESTIONS

Although the design and performance results of the dryer have been carried out, organoleptic testing and economic analysis of the process need to be added to increase information for the user community.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest with the research.

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