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# Design and Development of a Garlic Dryer (*Allium sativum* L.) with the Addition of Parafin as a Heat Storage Medium

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**ABSTRACT**

*Garlic is an important commodity as a basic spice for various dishes with several health benefits such as lowering blood pressure and improving immune system. Fresh garlic has a high moisture content of 60.9-67.8%, making it highly susceptible to microbial spoilage. The drying process is a critical post-harvest step for garlic that significantly influences product quality and shelf life. This study aims to design a garlic drying system enhanced with solar collector and parafin as a thermal storage medium. Parafin provides heat during periods of low sunlight, allowing continuous drying. The methodology includes the design, construction, and testing of the drying equipment. Functional tests demonstrate effective operation of the dryer components. The results of testing the dryer for drying garlic were able to reduce the water content of garlic from 60% wb to 11.2% wb for 8 h of drying. The use of paraffin has proven to be effective in helping to maintain the drying temperature, especially when the intensity of sunlight is reduced, so that the drying process remains optimal.*

## 1. INTRODUCTION

Garlic (*Allium sativum* L.) is an important commodity, apart from being used as a basic spice in various dishes, garlic has health benefits such as lowering blood pressure and improving the immune system (Fuadah *et al*., 2014; Wibowo, 1994). The need for garlic is still not balanced with domestic production, so Indonesia has to import most of its garlic needs from other countries (Septiana *et al*., 2022). In 2021, domestic garlic production will reach 2.8 thousand tons, combined with imports of 70.9 thousand tons, so that the total availability of garlic reaches 73.7 thousand tons, while the need for garlic is 45.2 thousand tons, resulting in a garlic stock surplus of 28.4 thousand tons. The volume of garlic imports will decrease in 2022, compared to the previous year. In November 2022, the actual import volume was recorded at 63.4 thousand tons, down 5.79% from 67.3 thousand tons in October 2022. When compared with the same period the previous year, the decline was more significant, namely 37.46% from 101.4 thousand tons in November 2021 to 63.4 thousand tons in November 2022 (BPS, 2023; Ministry of Trade, 2021).

Surplus garlic stock, which means that the amount of garlic available on the market or in warehouses exceeds consumer needs or demand in a certain period, this condition results in detrimental impacts such as the risk of spoilage, price reductions, losses for producers. Garlic when harvested has a water content of around 60.9-67.8% wb, so it is susceptible to rot due to microbial growth and activity (Samadi, 2000). To overcome this, it is necessary to carry out a drying process until it reaches a water content below 11.2% wb which can increase shelf life and maintain its quality and nutritional value.

Drying aims to reduce the water content to a certain limit so that the activity of microorganisms and enzymes that cause spoilage stops, thereby extending the shelf life (Husna *et al*., 2017). The drying process can be carried out traditionally by drying in the sun or using an artificial dryer. One of the artificial drying methods that has been applied to garlic is vacuum drying (Husna *et al*., 2017; Wahyu *et al*., 2024).

Currently, there are various garlic drying technologies, including instore dryers and vacuum freeze-drying. Instore dryers are designed to help farmers in the post-harvest process by combining drying and storage facilities equipped with temperature and humidity settings. This technology is able to reduce crop losses by up to 16% and keep damage levels below 10%, but has weaknesses such as complex use and high investment costs so it is more suitable for use by farmer groups or large companies (Badan Litbangtan, 2017; Rahma *et al*., 2021). Meanwhile, vacuum freeze-drying requires a long time, expensive equipment and high energy consumption and operational costs (Nelwan, 2021).

Dried garlic products are one way to overcome the decline in garlic prices. Dried garlic products are garlic that has been processed through a drying stage until the water content reaches less than 11.2%. There are several types of dried garlic products, including garlic powder, chopped garlic, granulated garlic and minced garlic. The advantage of dried garlic products is that they can increase the added value of the product and reduce the risk of losses for farmers when garlic prices fall. This is based on the efficiency of the drying process which consists of production capacity, ease of energy sources and environmental sustainability. In an effort to maintain the sales value and quality of garlic at the farmer level, a simple dryer is needed that can dry garlic until the water content reaches 11.2% wb with the addition of paraffin as a heat storage medium. In this dryer, the paraffin function can provide heat when hot from the sun decreases during the afternoon and evening so the drying process continues. The aim of this research is to design a drying device that can produce dried garlic products with good quality standards.

## 2. MATERIALS AND METHODS

The research was carried out from February to June 2023. The design, manufacture and testing of a garlic dryer was carried out at the Siswadhi Sopardjo Field Laboratory, Leuwikopo, Department of Mechanical and Biosystems Engineering, Bogor Agricultural Institute. Several test parameters include measuring temperature, humidity (RH), heat exchanger temperature, drying time and water content of garlic during the drying process. The dried material is kating garlic, which is most commonly sold on the market, has small cloves that grow in groups and has a strong and distinctive aroma.

### 2.1. Design Criteria

Design criteria refer to parameters or standards that must be met in the design process of a product. Design criteria are important to ensure that the tool being designed can function effectively and efficiently (Janjai *et al*., 2007; Jagedeesh *et al*., 2021). The design criteria needed to design a garlic dryer can be seen in Table 1.

Table 1. Design Criteria

| No | Engineering characteristics | Target |
|---|---|---|
| 1 | Drying temperature | 55-60°C |
| 2 | Stack thickness | 0.05 mm |
| 3 | Initial water content | 69% |
| 4 | Final water content of the product | 8% |
| 5 | Long drying time | 8 hour |

### 2.2. Research Stages

This research was carried out in several stages as presented in Figure 1. The initial stage began with identifying the problem or challenge to be solved. Next, a search for possible alternative solutions is carried out. This process involves exploring various options that can address the problem. After that, choose the most suitable alternative. The next step is to design the chosen solution. Then testing and analysis of the results are carried out. The flow of this process is as in the design of the dryer shown in Figure 1.

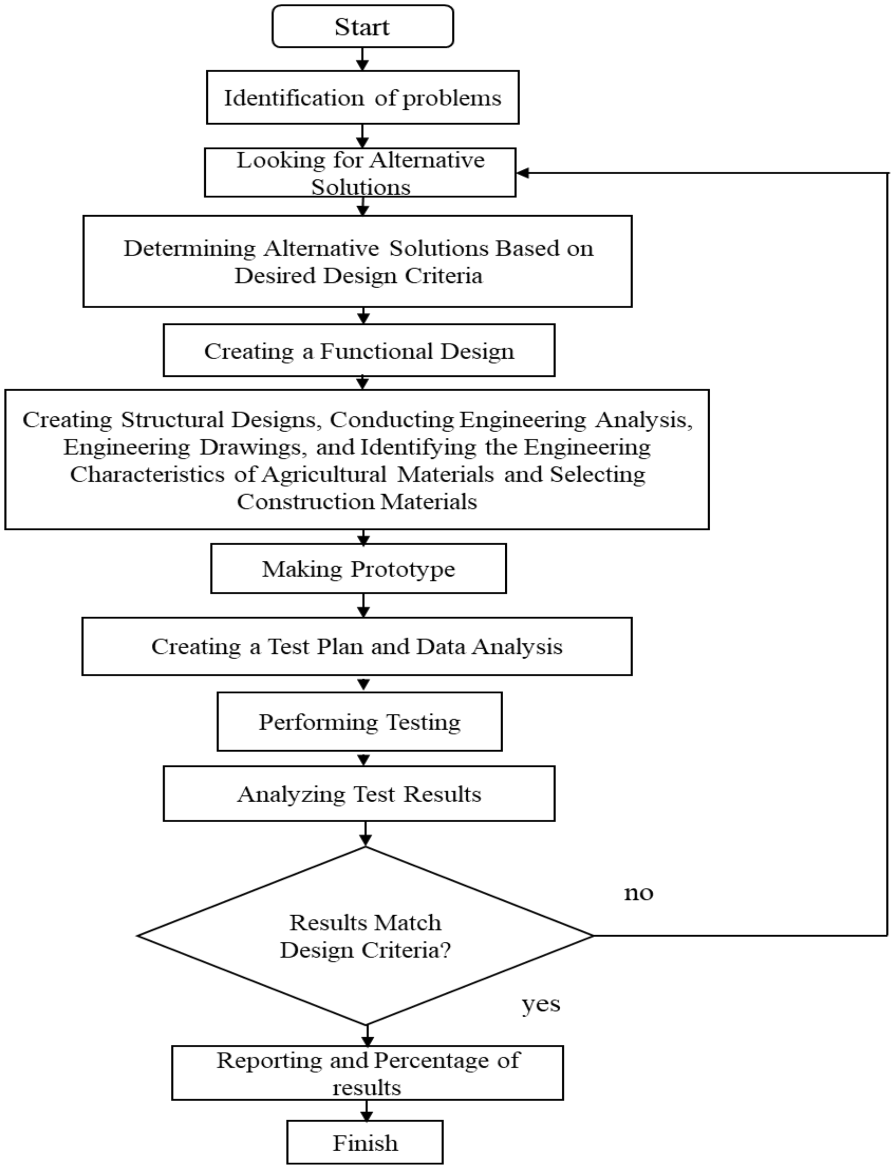


Figure 1. Flow diagram for the design of a garlic dryer

## 2.3. Functional Design

Functional design is a design process that focuses on identifying and developing the function of each component in a system or tool, the aim is to ensure that each part operates in accordance with the stated objectives (Priyadi, 2006). In the functional design of the dryer, the function of each component is identified as presented in Table 2.

Table 2. Functional Design

| No | Component | Function |
|---|---|---|
| 1 | Solar Collector | Media to capture sunlight so that it can produce heat for drying |
| 2 | Drying room | Captures heat from the sun so that the drying process occurs in the drying room, and protects the garlic from rain and dust/dirt contamination |
| 3 | Ventilator Turbine | Air exchanger in drying chamber |
| 4 | Drying rack | Container of garlic simplicia to be dried |

### 2.4. Structural Design

Structural design is a design process related to arranging and selecting materials and the physical form of a tool to ensure strength, stability and durability (Afrizal, 2006). In the design of this dryer, it has a maximum capacity of 3 kg, the energy source comes from the sun. Furthermore, the detailed structural design of the dryer can be seen in Figure 2.

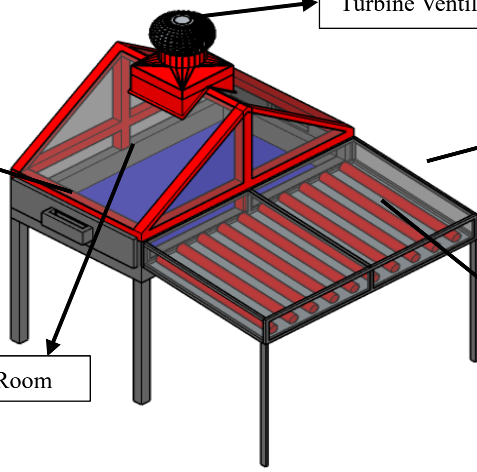


Figure 2. Structural design of the garlic dryer

Table 3. Structural Design

| No | Dryer Parts | Dimensions and Materials |
|---|---|---|
| 1 | Frame | The frame is made of angle iron with dimensions of 1.2 x 1.2 meters |
| 2 | Closing | Made of 5 mm transparent acrylic |
| 3 | Solar Collector | 1 piece, the collector cover is made of glass, the absorber is made of aluminum plate, and inside the collector there are 11.2 copper pipes with a length of 50 cm which contain paraffin. |
| 4 | Ventilator Turbine | Made of stainless steel. |

### 2.5. Technical Characteristics of Agricultural Materials

Analysis of the technical characteristics of the material being dried is important in the design of drying equipment because it allows a thorough understanding of the material to be processed. This allows the development of drying equipment that matches the characteristics of the material, increases drying efficiency, and ensures the integrity and quality of the resulting material. Furthermore, the technical characteristics of garlic are presented in Table 4.

Table 4. Engineering characteristics of garlic materials (Husna *et al*., 2017)

| Parameter | Value | Unit |
|---|---|---|
| Water content | 60.9-67.8 | % |
| Bulk density garlic | 478.75 | $kg/m^3$ |
| True density of fresh garlic | 1383 | $kg/m^3$ |
| True density of dry white | 1528 ± 26 | $kg/m^3$ |
| Simple thickness | 0.05 | mm |
| Segment length | 27.24 | mm |
| Diameter | 46.51 | mm |
| Specific heat | 3.17 | $kJ.kg^{-1}.K^{-1}$ |
| Latent heat | 196 | kJ/kg |

### 2.6. Dryer Testing

Testing of the designed dryer was divided into two, namely functional testing and performance testing. The functional test aims to ensure that all the main components of the dryer such as the ventilator turbine, solar collector and heat exchanger are functioning properly. The functional test procedure begins with equipment preparation such as ensuring all components are installed properly, checking the condition of the ventilator turbine, solar collector and heat exchanger to ensure there is no damage or leaks. This test is carried out with one test without load (garlic) so that the main focus is on assessing the functionality of these components. The results of this functional test provide an idea of the extent to which the influence of these two components influences the drying process. In this way, it can be a reference in improving the overall efficiency and performance of the drying machine. Meanwhile, the performance test aims to evaluate the performance of the dryer in reducing the water content of garlic and to test the ability of paraffin as a heat storage medium. The garlic drying process was carried out for 8 hours with one test according to the technical analysis calculations carried out. Meanwhile, paraffin testing was carried out without load until the temperature in the drying chamber equals the ambient temperature.

### 2.7. Measurements and Observations

#### 2.7.1. Drying Rate

The testing method is carried out by taking 5 samples of garlic before drying and measuring the initial water content of the material using a moisture tester, then taking 5 samples of the material after drying and measuring the water content of the material using a moisture tester, then the drying rate can be calculated using equation 1 (Djaeni , 2019).

$$LP = (\frac{M_0 - M_1}{t}) \tag{1}$$

where *LP* is hourly drying rate (%/h), $M_0$ is average water content before drying (%), $M_1$ is average water content after drying (%), and *t* is time (h) required to reduce the water content from $M_0$ to $M_1$.

#### 2.7.2. Water Content

The water content testing method begins by taking 7 samples diagonally, then measuring the water content of the material using a moisture tester. Measurements were carried out every hour, then the water content of the material was calculated using Equation 2 (Haryanto *et al*., 2023).

$$K_a = \left(\frac{m_t - m_k}{m_t}\right) \times 100\% \tag{2}$$

where $K_a$ is water content (%), $m_t$ is initial mass of material (kg), and $m_k$ is final mass of material (kg)

#### 2.7.3. Drying Air Rate

The total air mass required for the drying process was calculated using Equation 3 (Djaeni, 2019).

$$m_a = \frac{Q_t}{C_p \times (T_i - T_o)} \tag{3}$$

where $C_p$ is specific heat of air (kJ.kg$^{-1}$.K$^{-1}$), $T_i$ is air temperature entering the drying chamber (K), and $T_o$ is temperature of the air coming out of the drying machine (K).

#### 2.7.4. Solar Collector Analysis

The useful energy received by the solar collector can be calculated using equation 4 (Ahmar *et al*., 2023).

$$Qu = mC_p(T_{fi} - T_{f0}) \tag{4}$$

where *m* is mass flow rate of water (kg/s), $C_p$ is specific heat (kJ.kg$^{-1}$.°C$^{-1}$), $T_{fi}$ is inlet temperature (°C), and $T_{fo}$ is outlet temperature (°C).

## 3. RESULTS AND DISCUSSION

### 3.1. Dryer Prototype

The design results for the garlic dryer consist of tool frame, drying chamber, solar collector, heat exchanger, ventilator turbine, drying chamber door. The capacity of the dryer is 3 kg of garlic. The energy source comes from solar radiation which is then converted using a heat exchanger on the solar collector, then the air inlet hole on the solar collector as an air inflow which is then channeled through a ventilator as well as an air temperature outlet in the drying room. The drying room consists of a shelf with dimension of 0.8 $m^2$.

### 3.2. Functional Test Results

Dryer functional testing is an important stage in the development and design process. The purpose of this test is to ensure that each component that makes up the dryer functions properly and meets its stated purpose. The functional test was carried out without using a load, the functional test results can be seen in Table 5. The test results of the dryer components show that every part of the dryer works well. The solar collector in the dryer is capable of producing heat energy without load in the drying room with temperatures reaching approximately 70°C. This shows the ability of solar collectors to collect solar energy efficiently. In addition, the performance of paraffin is also very good. At 17.00 PM, when sunlight begins to decrease, paraffin is still able to produce heat energy until 20.00 PM. At that time, the temperature of the drying room was the same as the ambient temperature, indicating that the dryer was able to maintain the desired temperature within the expected time period. With these satisfactory test results, it can be concluded that the dryer has passed the quality test well. Each component functions properly and provides optimal performance during the testing process. This makes this dryer efficient in producing heat energy without load and can overcome the decrease in sunlight by using paraffin as an additional energy source. According to research conducted by Wahyu (2024), it requires the fastest drying time, namely 11 hours using a Rotary dryer and drying using the conventional method requires the longest time, namely 78 hours from the start of drying, whereas the designed garlic dryer is able to reduce garlic moisture content with only 8 hours of drying.

Table 5. Functional testing of dryers

| No | Testing Components | Results |
|---|---|---|
| 1 | Ventilator Turbine | Pretty good |
| 2 | Solar Collector | Good |
| 3 | Paraffin Performance | Good |

### 3.3. Drying Chamber Testing

Testing of the drying chamber was carried out by testing using a load and testing without a load. Load drying testing is important because it reflects real-world conditions of solar dryer use. In practical situations, the dryer will encounter resistance generated by the material being dried. Load testing allows evaluation of the tool performance in overcoming these resistances and ensures optimal drying efficiency. By testing the dryer with various loads representing different types of material, information can be obtained about the device capability to reduce moisture effectively and the time required to achieve the desired drying level.

No-load testing is also important because it provides an understanding of the basic performance of the solar dryer. Without load, the tool can operate at maximum level without having to overcome the resistance of the material being dried. This test allows assessing the thermal efficiency and power of the dryer in converting solar energy into heat and air flow. This helps in understanding the tool's ability to produce the temperature and humidity required for drying. No-load testing also allows monitoring of tool behavior under optimal conditions, which can be used as a comparison with load testing to evaluate tool performance under various operational conditions. By carrying out these two tests, comprehensive data are collected about the performance of the solar dryer and its ability to overcome the resistance of the material being dried. This information is important in developing and improving solar dryer designs, as well as in evaluating the energy efficiency and time required for the drying process. Thus, load and no-load drying tests play an important role in ensuring the quality and optimal performance of a solar dryer.

### 3.4. No-Load Testing

Testing of the temperature distribution in the dryer using paraffin as a heat storage medium was carried out by testing without load, starting from 11.00 WIB to 20.00 WIB. The no-load test is the first stage of testing, in this first stage of testing the temperature and RH in the drying room were observed, the average temperature in the drying room reached 58.6℃, with the humidity value in the drying room reaching 20.8%. Meanwhile, the environmental temperature ranges from 25.7℃ to 35.6℃, with a humidity of 51.6%-91%. The following is a comparison of the air conditions (temperature and RH) in the drying room and the environment, which can be seen in Figure 3. It can be observed the relationship between temperature and RH in the drying room. At the beginning of taking the temperature value was high and RH was low, this shows that the drying process was going well. However, after 16.00 WIB (16800-20400 seconds) the temperature decreases and RH increases in the drying room which is caused by reduced radiation, but in previous research the temperature of the drying room decreased at 14.00 WIB and continued with the use of biomass and LPG gas as heat source (Duffie *et al*., 1980). This drying shows that the use of paraffin as a heat storage medium is working well. Figure 4 shows that paraffin can maintain the temperature in the drying room until 16.10 WIT. The drying room temperature at 16.10 reached 41℃. In the graph below you can see the relationship between plate temperature, heat exchanger, drying room temperature, plenum, environmental temperature and drying room wall temperature.

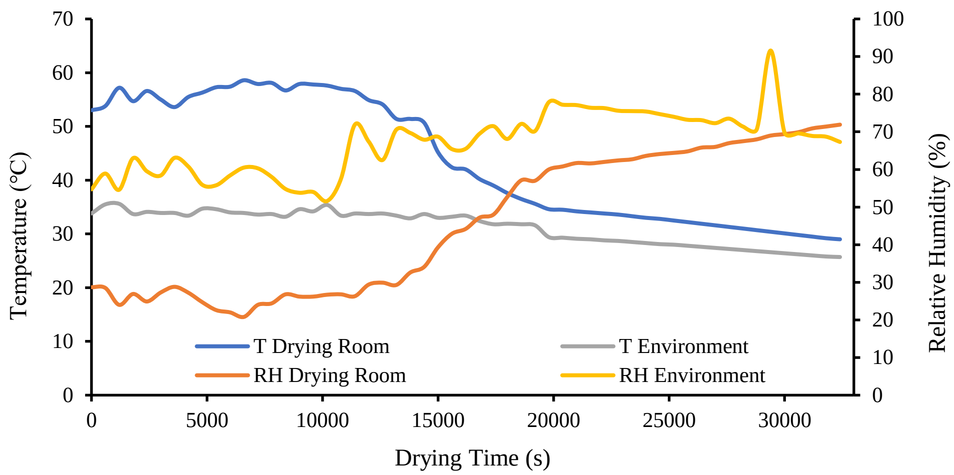


Figure 3. Graph of the relationship between temperature and RH for testing without load

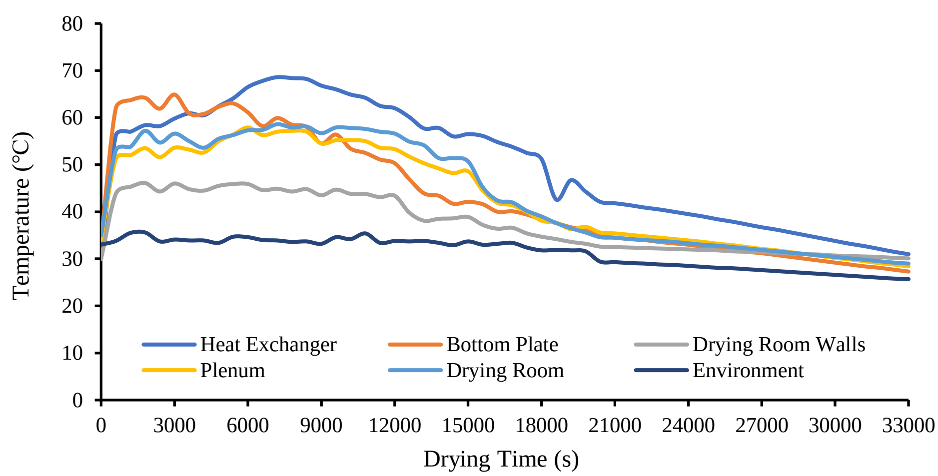


Figure 4. Distribution graph of test temperatures without load

Figure 4 shows the temperature changes over time on various components in the dryer, namely the heat exchanger, drying chamber walls, bottom plate, plenum and environmental temperature. The highest curve shows that the temperature in the heat exchanger reaches 70℃, the drying chamber wall temperature is lower than the heat exchanger, namely reaching 60℃, while the drying chamber temperature reaches 50℃. The temperature difference between the heat exchanger, the drying chamber wall and the drying chamber shows that the heat distribution is quite effective for drying garlic.

### 3.5. Testing with Load

At the start of data collection, the air temperature was recorded to be lower compared to the humidity (RH), which had a higher value. As time went by, it was seen that the temperature was increasing and the RH was decreasing, which indicated that the drying process was going well. The lowest temperature occurred at 16.30, namely 39.8℃, while the highest temperature was recorded at 13.00, namely 53.8℃. It can be seen in Figure 5 that at 16.30 (25,000 seconds) there was no longer any significant drying.

Under conditions when the temperature and RH begin to remain constant, the drying process is considered to stop because there is no longer a net change in the water vapor content in the air. In the drying process, the main goal is to remove excess moisture from the air to dry the target material or surface. When the temperature and RH are stable, it will show that the amount of water vapor that evaporates into the air is the same as the amount of water vapor that returns to the material. In this condition there is no significant change in the water vapor content of the air over time (Zemansky, 1986).

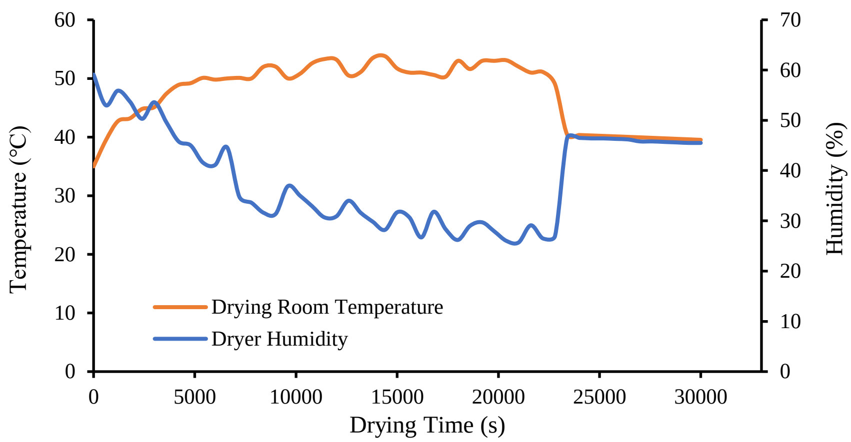


Figure 5. Graph of the relationship between test temperature and RH with load

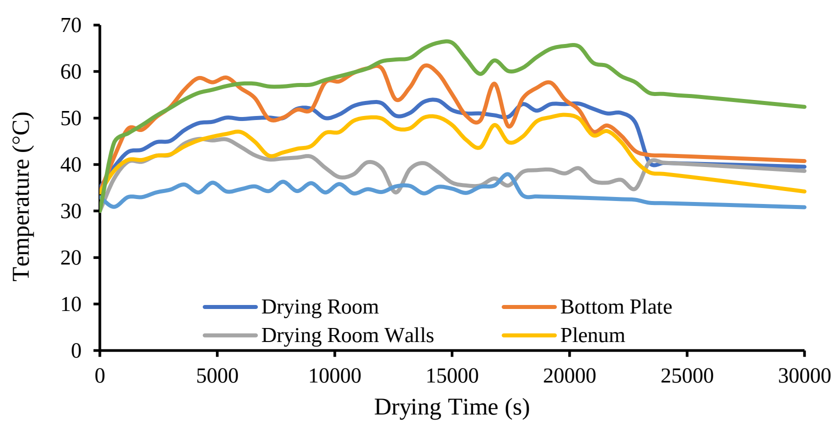


Figure 6. Test temperature distribution graph with load

Figure 6 shows the distribution of test temperatures with a load of garlic, it can be seen that the highest temperature was on the heat exchanger at 66.2°C at 13.00 WIT (14400 seconds), followed by the plate temperature which reached 61.2°C at 12.00 WIT (13800 seconds), while the temperature drying room reached 53.8°C at 13.00 WIB (14400 seconds), the temperature decreases as solar radiation decreases, but the temperature in the heat exchanger is still above 50°C even though the radiation has decreased, this phenomenon indicates that the paraffin used as a heat storage medium is working well.

### 3.6. Collector Performance Testing

Collector performance testing was carried out to determine the amount of solar irradiation that was able to be captured by the collector in the form of temperature increases in the paraffin circulated in the collector. Collector performance testing is one of the collector performance tests that has been designed. Testing the performance of the solar collector was carried out by inserting paraffin into a copper pipe, then the testing process lasted for 8 h. The paraffin (heat exchanger) temperature in the collector can be represented by the heat exchanger (HE) temperature. In Figure 7 it can be seen that the initial HE temperature is 30°C. The irradiation received in the test has a parabolic pattern, namely starting at 12.00 WIB (0-3600 s). The irradiation has a value of 773.54 W/m² so that at 13.00 WIB (4200-7800 s) irradiation continues to decrease until at 16.00 WIB (16800-20400 s) irradiation reaches 332 W/m². Then at around 17.50 WIT (21000-24600 seconds) solar radiation did not shine on the dryer so this could be proven at 17.50 WIT the irradiation reached -4.986 but at HE the temperature could still be maintained, namely 40°C, this phenomenon proves that paraffin is able to store heat well, in accordance with research by Ahmar *et al*. (2021) which states that the paraffin used to store heat can maintain the temperature of the drying room up to 5 hours when there is no solar radiation.

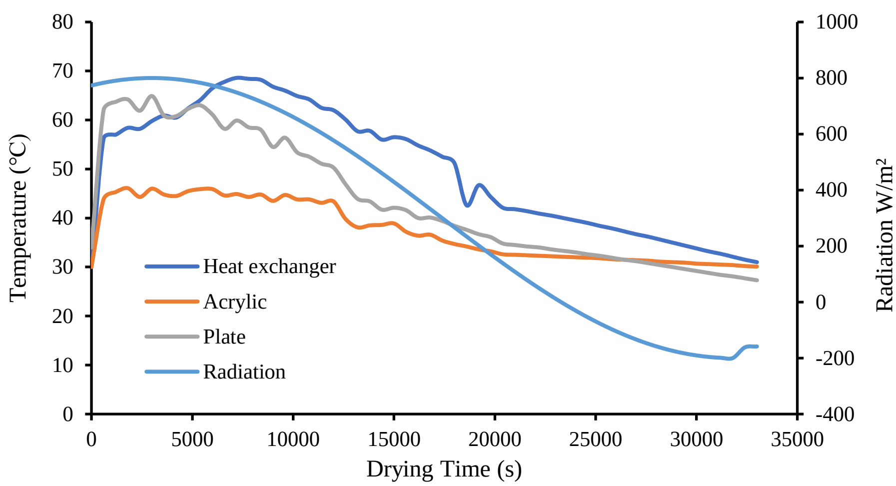


Figure 7. Solar radiation and the resulted of the collector temperatures

### 3.7. Product Water Content

After drying for 8 hours using a garlic dryer with paraffin as a heat storage medium, the final moisture content of the material was obtained with an average of 11.2% wb. During the day, the ventilator turbine on the dryer rotates with the help of the wind, so it can produce an air flow that directs heat from the collector room to the dryer room. However, in the afternoon when there is not enough wind, the ventilator turbine does not move, so the heat flow is hampered and most of the heat in the collector room cannot be transferred to the drying room.

The obtained water content of 11.2% wb is sufficient to increase shelf life, maintain quality and nutritional value, but to convert it into powder, a lower water content is needed (<10% wb). By further reducing the water content, garlic can be ground into a powder with a soft, long-lasting texture. Lower moisture content helps prevent the growth of microorganisms and maintains the quality of dried garlic. In this way, the resulting garlic powder will have a concentrate that has a strong aroma and a longer shelf life for food processing purposes. To obtain the drying rate, data on the final water content of the product is required. Carried out using the oven method for 1 hour to obtain a water content of 11.2% wb while the final water content target was 8% wb. can be seen in Table 6 below.

Table 6. Final product water content

| Sample Number | Weight (grams) | Initial Weight (grams) | Final Weight (grams) | Initial Water Content (%) | Final Water Content (%) | Drying Rate (%/Hour) |
|---|---|---|---|---|---|---|
| 1 | 2.25 | 2 | 1.75 | 62.5 | 12.5 | 50 |
| 2 | 2.25 | 2 | 1.77 | 61 | 11.5 | 49.5 |
| 3 | 2.28 | 2 | 1.79 | 60 | 10.5 | 49.5 |
| 4 | 2.23 | 2 | 1.79 | 60 | 10.5 | 49.5 |
| 5 | 2.26 | 2 | 1.78 | 60.5 | 11 | 49.5 |
| Average | | | | 60.8 | 11.2 | 49.6 |
| Average Drying Rate | | | | | | 6.2 |

After obtaining an average water content of 11.2%, a drying rate of 6.2%/hour was obtained. A drying rate of 6.2%/hour shows the percentage reduction in water content in the material during each hour of drying. This means that in every hour of drying, the water content decreases by 6.2%/hour from the initial water content. This drying rate gives an idea of how quickly the material loses water during the drying process. The higher the drying rate, the faster the material removes moisture and reaches the desired moisture content. In this case, the drying rate of 6.2%/hour indicates that the drying process is quite fast, because in one hour, the material loses about 6.2%/hour of its water content.

## 4. CONCLUSION

A garlic dryer designed to use paraffin as a heat storage medium can function well. The results of testing the dryer for drying garlic were able to reduce the water content of garlic from 60% wb to 11.2% wb for 8 h of drying. The use of paraffin has proven to be effective in helping to maintain the drying temperature, especially when the intensity of sunlight is reduced, so that the drying process remains optimal.

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