Deep bed drying performance on paddy using hybrid infrared-solar dryer

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Abstract. Hybrid infrared-solar dryer has a potential for drying fruits, vegetables, and grains such as paddy. This study aims to assess the performance of hybrid infrared-solar dryer on paddy in different of deep layer. Three different infrared heaters were used with a power of 25 W, 50 W, and 100 W. The hybrid infrared-solar dryer equipped with sensors placed in an open space so that sunlight can reach the drying chamber. The paddy samples were dried in different of deep layer (2 cm, 4 cm, 6 cm) until it reaches a moisture content of 14%. The input sensors in the drying chamber such as temperature, humidity, and moisture content were recorded using microcontroller and stored in Microsoft Excel® using the Parallax Data Acquisition tool. The algorithm was developed in order to control the heater from the input of temperature and humidity sensors by adjusting turn on/off relay. The study confirmed that the infrared heating power of 100 W is recommended for paddy drying if the ambient temperature is unfavourable (temperature less than 30°C). In general, the hybrid infrared-solar-dryer with a power of 25 W-100 W has a potential to dry paddy quickly at a thickness of 2 cm-6 cm with a time range of 90-150 minutes.

1. Introduction
Indonesia is a tropical country with excessive solar radiation. Indonesia's average daily radiation potential is about 4 kWh/m² which is ten times that of Germany and Europe [1]. This number can be utilized in various ways, especially in the drying of agricultural products. There have been many uses of solar energy for drying agricultural products in Indonesia, such as the use of the greenhouse effect dryer. This dryer is always influenced by solar heat irradiation; however, the disadvantage of this method is lack of temperature uniformity in the drying chamber.

In order to solve these problems, the combination of the greenhouse effect drier with infrared heaters is an alternative method. The infrared heaters have advantages such as: efficient use of energy used, temperature control can be carried out, uniformity of drying temperature so that it is expected to shorten drying time [2]. Infrared radiation is divided into three parts, namely: near-infrared (NIR), mid-infrared (MID), and far-infrared (FIR). The selection of infrared radiation depends on the product to be used. Materials that are organic and rich in water will easily absorb infrared radiation at wavelengths of 3 m and 6 m [3]. Thus, infrared drying is a potential method for drying fruits, vegetables, and grains such as paddy.

Infrared heater is a heating device that uses infrared as the main element in the drying process. This far infrared heater is shaped like a lamp, where this type of heater has a working system by producing
hot electromagnetic waves which are then directed to the material to be dried [4]. This drying system uses a drying chamber which has a far infrared heater on the roof with a fan that functions to circulate the hot steam in the drying chamber evenly, so that the material can be dried thoroughly. Through the drying process using this far infrared dryer, the material to be dried is much more sterile because it is located in the drying chamber and drying can take place optimally without the need to think about obstacles that occur if there is no sunlight. This study aims to assess the performance of hybrid infrared-solar dryer on paddy in different of deep layer.

2. Materials and methods

2.1. Hardware design
The design of the hybrid infrared-solar dryer is shown in Figure 1. The dryer consists of an infrared heater, a microcontroller, four temperature and humidity sensors, two computer fans, one relay, and a drying chamber. The length, width and height of the drying chamber are 50 cm x 50 cm x 30 cm, respectively. Two temperature and humidity sensors are placed inside the paddy chamber, and two temperature and humidity sensors are placed inside and outside of the dryer. Likewise, the grain moisture smart sensor was used to measure moisture content of paddy which placed on the top and inside layers of the paddy.

![Figure 1. Hybrid infrared-solar dryer design equipped with microcontroller and sensors.](image)

2.2. Software design
The Arduino IDE (Integrated Development Environment) program application is used for controlling the fan and infrared heater by writing the algorithm on the Arduino board. Based on Figure 2, firstly the drying system checks (initializes) the sensor such as: the infrared heater, fan, smart sensor grain moisture, temperature and humidity sensor. Then, the system checks the temperature, if the
temperature exceeds the predetermined temperature limit, the system will automatically turn off the infrared heater and turn on the fan. If the temperature is less than the set temperature limit, the system will automatically turn on the infrared heater and turn off the fan. Next, the system checks the grain moisture content using a grain moisture smart sensor. If the water content is less than the specified limit, the system will again check the temperature, and re-do the drying process until the specified moisture content is met. If the moisture content is less than the specified water content limit, the system will turn off the infrared heater and the fan will automatically stop after a few minutes, at this stage the drying process has been completed.

![Flowchart of hybrid infrared-solar dryer using infrared heater.](image)

**Figure 2.** Flowchart of hybrid infrared-solar dryer using infrared heater.

2.3. Hybrid infrared-solar dryer performance
The hybrid infrared-solar dryer was tested with various parameters in Table 1. The dryer performance was carried out until a moisture content of 14% was obtained using a water content measuring device. Dryer measurement results are recorded in Microsoft Excel® using the Parallax Data Acquisition tool
(PLX-DAQ). Drying temperature and humidity data recorded every 5 seconds, whereas the moisture content were measured every 30 minutes.

| No | Infrared heater power (W) | Paddy deep bed layer (cm) |
|----|--------------------------|---------------------------|
| 1  | 2                        | 2                         |
| 2  | 25                       | 4                         |
| 3  | 2                        | 6                         |
| 4  | 2                        | 2                         |
| 5  | 50                       | 4                         |
| 6  | 2                        | 6                         |
| 7  | 2                        | 2                         |
| 8  | 100                      | 4                         |
| 9  | 2                        | 6                         |

**Table 1. Infrared heater treatment based on deep bed layer of paddy.**

3. Results and discussion

3.1. Dryer hardware

The hybrid infrared-solar dryer can be seen in Figure 3. The dryer is equipped with two fans in the drying chamber, an infrared heater, a steam exhaust chimney, and a pull hook to open the top cover (roof) of the dryer. This dryer is designed to obtain a stable temperature during the drying process. In addition, the dryer is equipped with temperature and humidity sensors to obtain information on temperature conditions in real time in the drying room. The sensor is connected to a computer with the help of a microcontroller.

![Figure 3. Hybrid infrared-solar dryer design.](image)

3.2. Dryer software

The temperature and humidity data in the drying room is sent to a computer device using the help of a microcontroller. The data are displayed in Microsoft Excel® using the Parallax Data Acquisition (PLX-DAQ) tool [5]. The PLX-DAQ is able to send the input sensors in the temperature inside and
outside of the drying chamber very well. In this study, the data was sent to Microsoft Excel every five seconds until the drying process was stopped, whereas the PLX-DAQ has the ability to accommodate a maximum of 26 columns in Excel in real time [6]. The control system used can work well as shown in Table 2. According to Table 2, the set point is determined based on various temperature conditions. The system ordered to the sensor can run properly according to the set point that has been inputted into the program (sketch). This is proven when the program was running well, the results of the sensor readings that have been determined cause the heater to turn on and the fan to turn off, and vice versa. Figure 5 shows the maximum deviation limit to the set point applied.

**Table 2. Infrared heater and fan controlling in drying chamber.**

| Set point temperature (°C) | Test (°C) | Results          |
|---------------------------|-----------|------------------|
| 40                        | 35        | Heater On, fan Off |
|                           | 40        | Heater Off, fan On |
| 50                        | 40        | Heater On, fan Off |
|                           | 50        | Heater Off, fan On |
| 60                        | 55        | Heater On, fan Off |
|                           | 60        | Heater Off, fan On |

**Figure 4.** Temperature deviation against set point applied to hybrid infrared-solar dryer.

3.3. *Drying chamber temperature distribution without infrared heater*

The performance of the drying chamber was evaluated without heating and controlling the temperature by observing the temperature inside and outside the drying chamber. Based on Figure 5, the room temperature in the dryer slowly increased in temperature until it reached a peak of 42.4°C with an ambient temperature of 38°C. Fluctuations in drying temperature can be seen at 11:26 WIB, where when the ambient temperature of the dryer decreases to 36.9°C, it will be followed by a decrease in the temperature in the drying chamber to 40.5°C. In general, temperature fluctuations often occur during drying using solar heat [7–9].

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Figure 5. Distribution of temperature in the drying chamber and ambient temperature without using infrared heaters with a deep bed layer 2 cm (N = 460 samples).

3.4. Drying chamber temperature distribution using infrared heater

The temperature distribution in the infrared drying system is shown in Figure 6. The temperature distribution in the drying chamber shows relatively uniform. Moreover, the temperature distribution maintained stable according to the set point used. The temperature in the drying chamber has increased using 25 W of heater to a maximum limit of 40.7°C. Meanwhile, the temperature of the paddy is relatively stable at 38.4°C. The temperature difference between the ambient temperature and the drying chamber temperature at a power of 25 W was reached in the range of 5-12°C. The temperature difference using 50 W heater between the drying chamber and ambient temperature is higher than the 25 W heaters, which is in the range of 10-14°C.

In addition, the infrared heater using 100 W shows a better temperature distribution in the drying chamber compared to both 25 W and 50 W. The difference between the ambient temperature and the drying chamber temperature was in the range of 12-17°C. The infrared heater of 100 W can be used for paddy drying when the sun's heat is not enough for drying, therefore the heat from this heater able to increase the drying chamber temperature up to 42-47°C if the ambient temperature is 30°C. However, it is also necessary to pay attention to the use of energy so that the costs incurred by using higher power will not be a burden on the farmers. In general, the power of 25 and 50 W also has the potential to be applied, assuming that the ambient temperature is expected to be more than 30°C. For the Aceh region of Indonesia, it is known that the average maximum temperature from 2011-2015 is 34.7 °C [9], so that the utilization both 25 W and 50 W heaters is still relevant for this experiment.
Several studies related to paddy drying have been carried out, prototypes and performance of hybrid solar heating and photovoltaic heater paddy dryers with a temperature monitoring system with an average drying temperature of 35.28°C [10], 32.4°C [12], 46°C [13]. Control system design for paddy drying with solar collectors and heat storage with an average drying temperature of 35.6°C [13]. In this study, the average temperature in the drying room with a heater of 25 W and 50 W could reach 40°C and 48°C, respectively. While the 100 W heater can reach an average temperature of 58.7°C (Figure 7).

**Figure 6.** Drying chamber temperature, paddy temperature, and ambient temperature of hybrid infrared-solar dryer using 25 W, 50 W, and 100 W.
3.5. Moisture content of paddy during drying process
Measurement of moisture content was carried out using a standard grain moisture content meter, where the data collection process was carried out every 30 minutes until the grain moisture content reached 14%. Safe moisture content for paddy storage is 13% - 14% wb [15,16].

![Graph showing temperature rise using 100 W of infrared heater.](image)

**Figure 7.** Temperature rise using 100 W of infrared heater.

![Graph showing moisture content at various thicknesses of paddy using infrared heating.](image)

**Figure 8.** Moisture content at various thicknesses of paddy using infrared heating.
Based on Figure 8, it is known that the drying of paddy with a thickness of 2 cm only takes about 90 minutes. Meanwhile, with a thickness of 4 cm, it takes 90 minutes to dry (for 50 and 100 W), but it takes 120 minutes for a 25 W. Meanwhile, for a thickness of 6 cm it takes 120 minutes (for 50 and 100 W), and 150 minutes for a power of 25 W. In addition to measuring the water content, the color changes of the paddy can also be used to determine whether the paddy is evenly dry.

4. Conclusions
Hybrid infrared-solar dryer has a potential for drying deep bed layers of paddy (2 cm-6 cm). The study confirmed that the infrared heating power of 100 W is recommended for paddy drying if the ambient temperature is unfavorable (temperature less than 30°C). In general, the hybrid infrared-solar dryer with a power of 25 W-100 W has a potential to dry paddy quickly at a thickness of 2 cm-6 cm with a time range of 90-150 minutes.

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