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HEAT TRANSFER ANALYSIS CABINET-TYPE ERK SOLAR DRYER MACHINE FOR DRYING AGRICULTURAL PRODUCTS

Yayat Ruhiat ✉
Department of Physics Education[1]
yruhiat@untirta.ac.id

Yudi Guntara
Department of Physics Education[1]

[1]Universitas Sultan Ageng Tirtayasa
Jl. Raya Palka No. Km 3 str., Serang, Banten Province, Indonesia, 42124

✉**Coresponding author**

Abstract

The Cabinet-type ERK solar dryer is manufactured by a temperature distribution process so that the temperature inside the appliance is well distributed. The cabinet-type ERK solar dryer comprises several components to maintain the water content, including a drying oven, air blower, heat-resistant pipe, hot water pump, thermostat, heat exchanger, and heater. These tools are used to convert heat radiation into conduction or convection so that the dried agricultural products' water content is relatively low. The data needed to show the quality of the tool include temperature on temperature received by the wall (T_w), absorbent plate (T_p) and room temperature (T_r). And as for other supporting data including the environmental air/ambient temperature (T_a) and solar irradiation (I) for optimal tool usage time.

The experiment results for 5.5 hours, as many as 23 measurements with time interval 15 minutes, obtained a relatively unchanged temperature distribution. During that time, the average temperature received by the wall (T_w) was 41.26 °C, while the middle plate temperature (T_p) was 40.65 °C and room temperature (T_r) was 40.71 °C. Thus, the temperature in the Cabinet-type ERK solar dryer is well distributed. The distribution percentage between wall temperature and plate temperature is 98.52 %, while wall temperature and room temperature are 98.67 %. The result indicates that the Cabinet-type ERK solar dryer is potential as a drying device for agricultural commodities. It is hoped that the Cabinet-type ERK solar dryer will be an alternative to a drying system that can improve the quality of agricultural commodities for farmers in Indonesia.

Keywords: air blower, agricultural commodities, cabinet-type, dryer machine, drying oven, ERK solar dryer, heat radiation, heat transfer, heater, temperature distribution.

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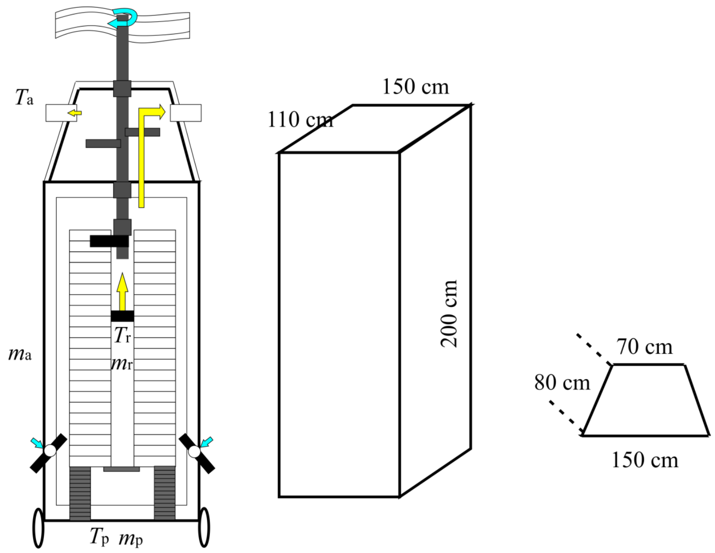
1. Introduction

Increasing the quality of agricultural products needs to be supported from several aspects, the drying process. In principle, to remove the water content in the commodity until it reaches a certain percentage, drying is carried out to be suitable for use. In general, the drying of agricultural commodities is done by drying or by using artificial dryers. With technology improvements, drying machines are used [1]. How to dry an agricultural commodity such as rice, cocoa, cloves, and others needs to be done to obtain quality agricultural products [2]. In general, by utilizing the power of natural sunlight, drying is done. However, drying carried out in this way, it is assumed that the water content of the dried product is still relatively high, although that the cost is relatively cheap is recognized [3]. In addition, several other weaknesses include depending on the weather [4], difficulty to control [5], requiring a large drying area [6], easily contaminated [7], it takes a long time [8]. Vice versa, the water content is relatively low, but the cost is high when using solar thermal drying through a solar collector [9] and steam heat from a coal-fired boiler [10].

It was referring to the two weaknesses of the method. Through this research, the researchers tried to focus in developing the effective and efficient dryer. It is necessary to make a more effective and efficient dryer with the biggest capacity in the smaller devices. The dryer that is possible, the Cabinet-type ERK Solar dryer model, is developed. This solar dryer utilizes solar energy so that the cost is relatively cheap and uses pipes and other components to keep the water content relatively low. The Cabinet-type Solar ERK dryer comprises several parts to maintain the water content, including drying oven, blower, heat-resistant pipe, hot water pump, thermostat, heat exchanger, and heater. These tools are used to convert radiant heat into conduction and convection so that the water content of dried agricultural products is relatively low. Several rice dryers are similar to Cabinet-type ERK solar dryers, including spin dry-pad and rack-type dryers. Spin Dry-Pad designed by [11], the dryer runs electrically with automatic temperature control. Later, a rack-type dryer was designed by [12]. The tool uses a hybrid rack by utilizing solar energy and a mixture of coconut straw and coir biomass designed with an unloading system. The difference between the working system of the Cabinet-type ERK solar dryer with the two tools is in the temperature distribution process in the dryer, so there is a difference in the drying process. It is hoped that the Cabinet-type ERK solar dryer will be an alternative for a drying system that can improve the quality of agricultural commodities for farmers in Indonesia. This tool was used to extend the shelf life of agricultural products. The principle of storage in this tool was to maintain the water content.

2. Materials and methods

The specifications and blueprint of the Cabinet-type ERK solar dryer are shown in **Fig. 1.**



a *b* *c*

Fig. 1. Design of solar dryer:
a – cabinet-type ERK solar dryer; *b* – bottom of dryer; *c* – top of dryer

Fig. 1 shows design of solar dryer. In **Fig. 1, *a*** it can be seen that the incoming solar heat is distributed by the rotating device so that every cell in the device receives heat. The dryer is made with a height of 2 meters and a width of 1.5 meters, as shown in **Fig. 1, *b***. Meanwhile, the cover is at the bottom 1.5 meters and at the top 0.7 meters, as shown in **Fig. 1, *c***. The data needed include:

a) solar radiation, humidity, ambient temperature, oven wall temperature, fluid temperature;

b) air temperature and airflow velocity in the drying chamber at each period, according to the type of commodity being dried;

c) drying capacity, drying time, initial moisture content, final moisture content.

Meanwhile, to determine the temperature of each cell in the Cabinet-type ERK solar dryer, an analysis of the temperature distribution was carried out as follows:

1. Temperature on absorbent plate.

The temperature distribution on the absorbent plate, expressed by (1):

$$T_p = T_r e^{-Qt} + \left(1 - e^{-Qt}\right)\frac{QT_r + S}{Q}, \qquad (1)$$

with

$$Q = \frac{h_i A_p}{m_p C_{pp}}, \text{ and } S = P600\sin\left(\frac{\pi t}{8} + 300\right) - R\left(T_r - T_a\right).$$

2. Room temperature.

Room temperature in the dryer using the (2):

$$T_r = T_{ro}e^{-At} + \frac{\left[T_a\left(\frac{\dot{m}_u}{m_r} + \frac{UA_w}{m_r C_{pa}}\right) + T_p \frac{h_i A_p}{m_p C_{pa}}\right]}{\left[\frac{\dot{m}_u}{m_r} + \frac{h_i A_p}{m_r C_{pa}} + \frac{UA_w}{m_r C_{pa}}\right]}\left(1 - e^{-At}\right). \quad (2)$$

The (2) can be written as,

$$T_r = T_{ro}e^{-At} + \frac{B}{A}\left(1 - e^{-At}\right). \quad (3)$$

3. Environmental air/ambient temperature.

The environmental air temperature can be obtained by using the (4):

$$T_a(t) = 4\sin\left(\frac{\pi t}{8} + 20\right). \quad (4)$$

3. Result and discussion

Based on the experimental results from 9.30 to 15.00 (for 5.5 hours), temperature data was obtained during that time. Plate temperature was analyzed using (1) as shown in **Table 1.**

Table 1

Plate temperature in the dryer

Time	*T* wall (T_w)	*T* plate (T_p)
9.30	37.2	38.4
9.45	39.2	37.5
10.00	44.4	39.5
10.15	42.7	39.6
10.30	41.3	39.1
10.45	43.1	40.0
11.00	44.4	40.3
11.15	43.7	39.1
11.30	43.7	39.5
11.45	43.4	40.0
12.00	43.4	40.9
12.15	42.6	41.5
12.30	42.7	41.4
12.45	43.7	42.5
13.00	43.2	44.3
13.15	41.6	46.3
13.30	41.4	47.9
13.45	42.4	45.0
14.00	41.0	42.1
14.15	39.9	39.4
14.30	36.9	38.8
14.45	34.3	37.3
15.00	32.8	34.6

And room temperature was analyzed using equations (3) as shown in **Table 2**.

Table 2
Room temperature in the dryer

Time	T_r under (bk)	T_r under (bb)	T_r upper (bk)	I (W/m^2)
9.30	36.6	31.6	46.3	601,42857
9.45	39.7	31.6	46.3	614,57143
10.00	42.3	34.6	53.6	743,42857
10.15	40.5	33.3	49.8	477,85714
10.30	41.5	33.7	52.6	689
10.45	42.4	34.1	53.6	725,28571
11.00	42.9	34.1	54.3	666,28571
11.15	42.7	33.9	52.9	640,28571
11.30	41.9	33.7	51.2	419,71429
11.45	41.7	33.3	50.5	354,57143
12.00	41.3	33.1	49.3	326,14286
12.15	40.8	32.8	48.7	302,42857
12.30	41.0	32.7	48.4	344,57143
12.45	41.0	33.1	49.1	412,71429
13.00	41.4	33.4	49.8	437,14286
13.15	42.0	33.6	50.6	468,85714
13.30	44.3	34.6	47.7	490
13.45	42.0	33.8	49.6	399,57143
14.00	41.0	33.0	47.9	316,57143
14.15	37.1	31.8	44.4	299,28571
14.30	38.8	32.3	42.8	215,42857
14.45	38.2	31.6	40.2	144,28571
15.00	35.3	30.3	37.4	61,71428

Based on **Tables 1, 2** the wall temperature (T_w), plate temperature (T_p), and room temperature (T_r) in 5.5 hours for 23 measurements obtained a relatively unchanged temperature distribution. During this period, the average temperature received by the cabinet-type ERK solar dryer wall was 41.26 °C while the plate and room temperatures were 40.65 °C and 40.71 °C. Thus the temperature of the cabinet-type ERK solar dryer is well distributed. A good temperature distribution will cause the drying of the harvest to be evenly distributed so that nothing is burnt [13]. The percentage distribution between wall temperature and plate temperature is 98.52 %, while between wall temperature and room temperature is 98.67 %. The high room temperature condition is the accumulation of plate temperature and wall temperature. This shows that the cabinet-type ERK solar dryer has the potential as a dryer for agricultural commodities.

To calculate the ambient air temperature, measurements were made from 9.30 to 15.00 with time interval t = 15 minutes = 900 seconds. The results of the analysis using (3) are shown in full in **Table 3**.

Based on **Table 3**, the ambient temperature has implications for the temperature received by the tool wall. This is in line with [14], if there is no limiter, then the ambient temperature will affect the system temperature.

In **Table 2**, it appears that the ambient temperature fluctuated and experienced a deviation of 4.08 %. The variation will have implications for the temperature distribution in the room. The sun's temperature experiences strong fluctuations throughout the year due to the greenhouse effect [15]. Therefore, the Cabinet-type ERK solar dryer does not decrease the indoor temperature distribution; it must maintain the ambient temperature properly.

Table 3
Ambient temperature state

Time	sin(π*t*/8+20)	$T_a(t)$
9.30	0.3420	1.368
9.45	0.9397	3.759
10.00	–0.3420	–1.368
10.15	–0.9397	–3.759
10.30	0.3420	1.368
10.45	0.9397	3.759
11.00	–0.3420	–1.368
11.15	–0.9397	–3.759
11.30	0.3420	1.368
11.45	0.9397	3.759
12.00	–0.3420	–1.368
12.15	–0.9397	–3.759
12.30	0.3420	1.368
12.45	0.9397	3.759
13.00	–0.3420	–1.368
13.15	–0.9397	–3.759
13.30	0.3420	1.368
13.45	0.9397	3.759
14.00	–0.3420	–1.368
14.15	–0.9397	–3.759
14.30	0.3420	1.368
14.45	0.9397	3.759
15.00	–0.3420	–1.368

The Cabinet-type ERK solar dryer is a non-isolated system so that there will be an interaction between systems. Therefore, the state of the ambient temperature will affect the room temperature. The relationship of room temperature during the experiment is shown in **Fig. 2**.

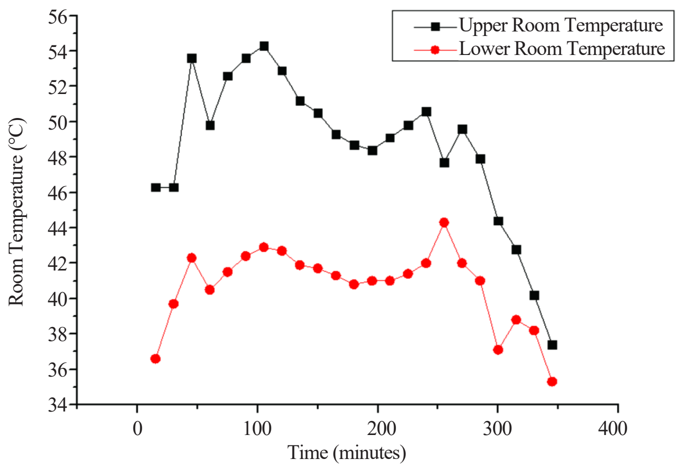


Fig. 2. The relationship between room temperature and time during the experimental process

It appears that there is a difference between the upper room temperature and the lower room temperature. During the experiment, the average upper room temperature was 48.56 °C, while the lower average temperature was 40.71 °C. The decrease in room temperature in the Cabinet-type

ERK solar dryer between the top and bottom is 16.16 %. The temperature drop is relatively small, but it should be avoided, so that room temperature distribution at the top and bottom remains stable. From **Fig. 2**, it can be seen that the room temperature at the top is higher than the room temperature at the bottom; this is because the temperature in the room is not well distributed, so there is always a temperature difference between the top and the bottom. For that, it is necessary a tool that serves to distribute the temperature in the room. The device can be in the form of an automation system [11] or using a microcontroller-based hybrid heating [16]. Furthermore, the relationship between solar irradiation and time during the experiment is shown in **Fig. 3**.

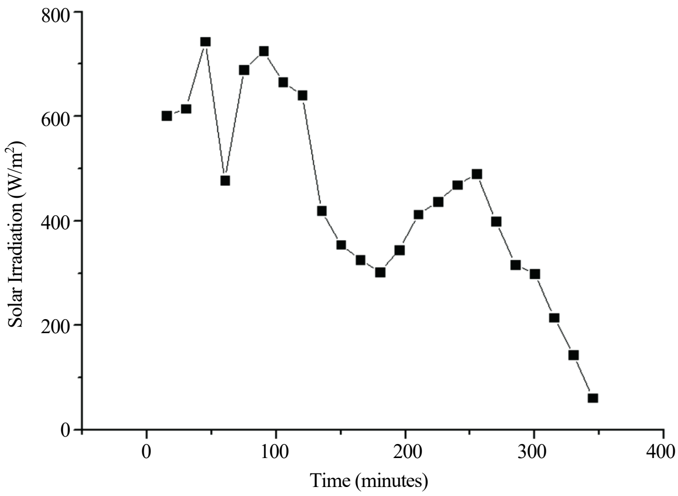


Fig. 3. The relationship between solar irradiation and time during the experiment

Instantaneous solar irradiation (I) is maximum at 10.00 with solar irradiation of 743,42857 W/m^2, while the minimum is at 15.00 with solar irradiation of 61.71429 W/m^2. From **Fig. 3**, it can be seen that the solar irradiation (I) is decreasing in the afternoon, this is in accordance with the research of [17], which explains that the shift is also caused by the position of the Sun.

4. Conclusion

During the experiment, from 9.30 to 15.00, the distribution of wall temperature (T_w), plate temperature (T_p), and room temperature (T_r) remained relatively unchanged. The percentage distribution between the wall temperature and the plate temperature is 98.52 %, while the wall temperature and room temperature are 98.67 %. The high room temperature condition is an accumulation of plate temperature and wall temperature. Changes in room temperature occur due to changes in plate temperature and changes in ambient temperature. Changes in room temperature due to ambient temperature generally occur in the upper and lower rooms. The decrease in room temperature in the Cabinet-type ERK solar dryer between the top and bottom is 16.16 %. The reduction in temperature is relatively small, but it should be avoided so that the distribution of room temperature both at the top and bottom remains stable. So, the distribution percentage between wall temperature and plate temperature is 98.52 %, while wall temperature and room temperature are 98.67 %. The result indicates that the cabinet-type ERK solar dryer is potential as a drying device for agricultural commodities. It is hoped that the Cabinet-type ERK solar dryer will be an alternative to a drying system that can improve the quality of agricultural commodities for farmers in Indonesia. It can be indicated that the implementation of this equipment application massively in increasing the capacity of agricultural productivities. This equipment can be applied with the bigger capacity using the small devices as one of the effective and sufficient productivities in agricultures.

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