Application of wavy absorber plate in solar dryer for higher drying speed in solar food dryer

M. Syafwansyah Effendi*, Ahmad Hendrawan, M. Khafidz Arifin
Mechanical Engineering Department, State Polytechnic of Banjarmasin
Brigjen H. Hasan Basri Komplek ULM, Kayu Tangi, Banjarmasin, Indonesia
*Email: msyafwansyah@poliban.ac.id

Abstract: Conventional food drying by using ambient air is the oldest and widely applied method to preserve agriculture product. This method, however, shows several challenges, e.g. contamination problem, inhomogeneous drying process, difficulty in control of water content which may lead to product degradation. Contamination during this method could be due to many factors, e.g. dirty air, insect, wind which may carry out garbage and animals’ sewage and rain. An alternative solution to overcome these challenges is by developing solar dryer method. This method is widely applied particularly in the area with abundant supply of solar energy. In this research, solar dryer is equipped with wavy plate consisting of two ducting. Two ducting design is expected to result in higher drying temperature compared than one ducting. The research was worked out through experimental method. Data of solar radiation, temperature of ambient air and drying room collected in this research was then synchronized with speed of drying process. The prototype developed in this research showed that drying speed could achieve 8.51% per hour.

Keywords: solar dryer, drying speed, flat plate air heater, heat absorber

1. Introduction
About 20-25% from 6 Billion world population do not have access to daily food [1]. Globally, it is estimated that app. 30-25% of vegetables, fruits and other foods are uneatable due to decay. Food preservation is offered as an optimistic solution to preserve these foods. According to Lakshmi et al. [2] food drying is a complicated process involving heat and mass transfer between ambient air, food surface, and internal part of food. Phadke et al. [3] reported that most population in developing countries involve in agriculture sector while almost 80% of food is cultivated by traditional farmer whose limited access to modern technology and method. These farmers only apply traditional drying method, i.e. drying the agriculture product by harvesting the heat of solar energy. This method however exhibits several weakness, e.g. contamination, inhomogeneous drying, uncontrollable water content, which degrade product quality. Contamination in this method could be due to dirty air, rain, wind, dust, animal activity, or garbage. Other challenges for this traditional drying method are due to uncontrollable food quality, uncontrollable water condition and wide drying area. Should these challenges be managed, the food quality will drastically decrease. This circumstance results in uneatable preserved food.
Drying method applying advance drying machine may improve quality of dried food. This method however requires high input energy and good process control which is difficult to be applied particularly in rural and remote areas due to several reasons, e.g. lack of electricity grid or fuel supply. Biomass, e.g. wood, rice husk, can also be used as alternative heat source to overcome these challenges.

An alternative solution to overcome lack of electricity and fuel supply for modern drying machine is by using solar dryer. This method can be applied in area whose abundant supply of solar energy. The use of solar dryer delivers several advantages, e.g. less costly, can be used in area with limited supply of electricity and fuel, limited contamination, protected environment from rain, dust and wind. However, challenges remain to achieve good process control.

Mahmood [4] evaluated characteristic of charging and use of two solar collectors. In his experiment, the solar collector was designed constant air flow rate at 0.0375 kg s⁻¹. Çelen and Karataser [5] investigated drying machine applying micro wave of solar energy. It was reported that this method shortened drying period and required less energy. Elbasher et al. [6] designed drying unit with varied mixture between normal room air and hot air, due to solar exposure. Shibly [7] compared performance between traditional drying process and drying process using solar energy. Zoukit and Ferouali [8] developed a forced-convection drying machine by utilizing heat from solar energy. The air flow used in that research was 0.027 kg s⁻¹.

Morad et al. [9] designed a greenhouse drying system by using two fans (Figure 1). The performance of greenhouse drying system was analysed based on data of air flow rate, initial weigh of dried material, e.g. peppermint, drying rate, drying efficiency, product quality and drying cost. It was reported that drying of peppermint leaf was much longer when peppermint branch was also dried. Thus, drying duration was shorter when peppermint leaf only was dried which leads to higher quality of oil extracted from peppermint leaf. When fan inside the greenhouse was fully operated, drying speed of peppermint leaf increased by 24.8%.

Jitjack et al. [10] compared performance of two greenhouse drying systems for rubber sheet drying, i.e. parabolic-shaped greenhouse (PG) (Figure 2) and parabolic greenhouse with the additional area-enhanced panels (PGEP). The dried material was rubber. The dimension of PG prototype was 2×3.5×1.5 m³ (W×L×H) and dimension of PGEP prototype was 3×3.5×1.5 m³ (W×L×H). Greenhouse cover was made from polycarbonate sheets. It was reported that temperature for PGEP system was 5 °C higher that of PG system. PGEP system also exhibited higher thermal efficiency and shorter drying duration than PG system. For rubber sheet drying, duration in PG system was 5 days while in PGEP system was only 1.5 days.
Figure 2. Solar dryer parabolic greenhouse [11]

2. Method and Material
Solar dryer in this research was designed based on author survey at many rural areas in South Kalimantan. Solar dryer in this research was therefore designed to achieve high drying speed and high temperature. In order to achieve this objective, heat absorber whose wavy plate and two ducting was investigated. The two ducting design was expected to increase drying temperature than that of a single ducting. The measurement devices, i.e. digital thermometer, pyrometer and solar power meter were installed and the data were recorded. Drying speed is calculated from initial mass ($W_i$), weight after particular period of time ($W_{t+1}$) and drying duration ($t$) (equation 1) [11].

$$\frac{dW}{dt} = \frac{W_{t+1} - W_t}{t} \times 100\%$$ (1)

Figure 3. Two dimensional model of prototype solar dryer
Figure 4. Three dimensional model of prototype solar dryer

The design of prototype solar dryer is shown in Figure 3 and Figure 4. Solar energy is absorbed by the wavy plate. The absorbed energy heats air entering the system due to negative pressure created by blower. The heated air dries up the material and release the evaporating water to the outside through the upper part of the dryer.

In this research, temperature of drying room, solar radiation, ambient air temperature and air humidity and condition of dried material was measured and recorded every 10 minutes. The measurement was worked out only from 11.40 am until 3 pm. After all these data were recorded, drying speed was calculated based on the initial and final weight of the dried material.

3. Result and discussion
Energy collected is function of the solar energy depending on several condition, hours, weather condition, etc. In the beginning, the solar energy is in direct contact with the upper surface of wavy plate. Some energy is absorbed by the plate material which increases the plate temperature. Some energy is transferred and reflected. The air is heated either by transferred and reflected solar energy directly or by heat transfer from the heated wavy absorber plate. The intensity of solar energy absorbed by the collector depends on transmissivity, absorbency and reflectiveness
of the absorber plate material. Wavy absorber plate is used in this research due to its unique reflection characteristics. In wavy absorber plate, the solar energy will be reflected many times (Figure 5). When flat absorber plate is used, this repetitive energy reflection cannot occur.

![Illustrated energy reflection on the surface of wavy absorber plate (left) and flat absorber plate (right)](image)

The result shows that solar radiation decreased for particular period which was possibly due to cloud disturbance. The average solar radiation was 710.62 W m\(^{-2}\) and its highest value was 1,321 W m\(^{-2}\) occurred at 12.20 am. The average and highest ambient temperature were 36.06 °C and 38 °C respectively. The average and highest temperature of absorber surface were 37.90 °C and 39.7 °C respectively. The temperature of absorber surface in this research shows only small deviation with result obtained by Ramadhan et al. [12]. Meanwhile, the average air humidity was 40.91 %.

**Table 1.** Measurement result of solar radiation, ambient temperature, drying room temperature, temperature of absorber surface and air humidity

| No. | Time     | Solar radiation [W m\(^{-2}\)] | Ambient temperature [°C] | Drying room temperature [°C] | Temperature of absorber surface [°C] | Air humidity [%] |
|-----|----------|---------------------------------|--------------------------|-----------------------------|-------------------------------------|-----------------|
| 1   | 11.40.00 | 1,189                           | 36.2                     | 38.5                        | 35.8                                | 43              |
| 2   | 11.50.00 | 1,186                           | 37                       | 39                          | 41.5                                | 37.7            |
| 3   | 12.00.00 | 1,227                           | 38                       | 38.1                        | 39.9                                | 37.5            |
| 4   | 12.10.00 | 244                             | 37.5                     | 38.3                        | 37.4                                | 37              |
| 5   | 12.20.00 | 1,321                           | 37                       | 37.9                        | 40.9                                | 38              |
| 6   | 12.30.00 | 183                             | 37.2                     | 36.9                        | 34.1                                | 39              |
| 7   | 12.40.00 | 1,171                           | 36.4                     | 38.9                        | 41.9                                | 39              |
| 8   | 12.50.00 | 1,238                           | 37.3                     | 39.7                        | 41.8                                | 38              |
| 9   | 13.00.00 | 282                             | 37.2                     | 36.4                        | 35.5                                | 38              |
| 10  | 13.10.00 | 228                             | 36.7                     | 36                          | 34.8                                | 38              |
| 11  | 13.20.00 | 1,151                           | 37.4                     | 39.2                        | 41.3                                | 38              |
| 12  | 13.30.00 | 212                             | 36.7                     | 36.3                        | 35                                  | 39              |
| 13  | 13.40.00 | 149                             | 35.4                     | 35.4                        | 35.5                                | 43              |
| 14  | 13.50.00 | 195                             | 35.1                     | 36                          | 35.3                                | 45              |
| 15  | 14.00.00 | 1,009                           | 31.5                     | 38                          | 39.5                                | 45              |
| 16  | 14.10.00 | 960                             | 36.4                     | 39.1                        | 40.2                                | 43              |
| 17  | 14.20.00 | 890                             | 36.7                     | 38.5                        | 37.2                                | 42              |
| 18  | 14.30.00 | 819                             | 35.5                     | 38                          | 36.1                                | 44              |
| 19  | 14.40.00 | 615                             | 32.5                     | 38.6                        | 36.3                                | 45              |
| 20  | 14.50.00 | 136                             | 34.8                     | 38.2                        | 36.4                                | 45              |
Figure 6. Solar radiation, ambient temperature, temperature of drying room, and air humidity

The dried material used in this research was sliced garlic. Data of solar radiation, ambient temperature, temperature of drying room, temperature of absorber surface and air humidity was recorded and presented in Table 1 and Figure 6. The drying speed determined by equation 1 was 8.51 % per hour. It informs that when the initial weight of dried material is 10 kg, the final weight will be 8.857 kg after 3 hours drying. In this condition, the water content will decrease by 1.143 kg. However, this drying speed is valid only for this particular dried material. Should the dried material change, the drying speed process should be investigated to determine the drying speed for this new material. In addition, this prototype design however should be further investigated to obtain higher drying speed.

4. Summary and future research activity

The advance drying system is required to decrease product contamination and to increase the drying speed. This research successfully designed and tested an optimized solar drying system required for food preservation. The result showed that temperature of drying room increased and the water content of sliced garlic, as the dried material, could be decreased. The drying speed achieved through the design in this research is 8.51 % per hour. More experimental activity using various foods needs to be worked out to further evaluate the performance of this prototype design.

Future research is important to increase the drying speed, e.g. by understanding the air flow above the absorber plate, heat transfer analysis and influence of blower speed on drying speed. These future research activities can be worked out either through experimental research or through computational fluid dynamics (CFD) simulation.
5. Acknowledgement

Financial support for this research project from the Institute for research and community services (LPPM) of State Polytechnic of Banjarmasin (Politeknik Banjarmasin), is acknowledged.

6. References

[1] Atul P H B., Patel H, Shah S A 2013 Int. J. Eng. Res. Technology Vol. 2 Nr. 1 19-23
[2] Lakshmi D V N, Mohapatra S S, and Das H C 2016 Appl. Mech. Mater. ISSN 1662-7482. Vol. 852 707-711
[3] Phadke P C, Walke P V, and Kriplani V M 2015 ARPN J. Eng. Appl. Sci.. Vol. 10 Nr. 8. 3360-3371
[4] Mahmood AS 2019 Journal of Engineering” Vol. 25 Nr. 2. 1-17
[5] Çelen S and Karataser M A 2019 Foods Vol. 8. 1–15
[6] Elbasher H A G, Abdalla B K, and Mohamed A A 2019 EJERS. Eur. J. Eng. Res. Sci.. Vol. 4. Nr. 1. 24–31
[7] Shibly A H 2019 Austin Publ. Gr. Vol. 4. Nr. 1 0-4.
[8] Zoukit A and El Ferouali H 2019 J. Energy Syst. Vol. 3. Nr. 1. 1–13
[9] M M Morad, A El-Shazly, K I Wasfy, Hend A M El-Maghawry. 2017 Renew. Energy. Vol. 101 992–1004
[10] S. Jitjack, K. Thepa, K. Sudaprasert, P.Namprakai. 2016 Energy Build. Vol. 124. 179-193
[11] Q A M O Arifianti., M R Abidin., E F Nugrahani., K K Ummatin, 2018 Jurnal Rekayasa Mesin Vol. 9. Nr. 3 211–220
[12] Ramadhan N, Soeparman S,Widodo A, 2017 Jurnal Rekayasa Mesin Vol.8 Nr.1 15- 22