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Thermal efficiency of vertical and horizontal-finned solar collector integrated with forced air circulation dryer for Apple as a sample

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ABSTRACT

In this article, an experimental estimation of thermal efficiency of horizontal and vertical-finned double-pass solar air collectors integrated with drying chamber has been carried out. The rig consists of two main parts as solar collector and dryer. The system was installed in the laboratory of Szent István University, Gödöllő, Hungary. The absorbers were made from a copper integrated fins in horizontal and vertical directions. The test results showed that the daily efficiency increased by 10% when the direction of fins have been changed from vertical to horizontal. After 5 h drying of 2 kg apple slices, the final weights were 1.16 and 1.37 kg by using horizontal and vertical-finned collectors, respectively.

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KEYWORDS

Drying; efficiency; horizontal fins; solar collector; vertical fins

Introduction

The use of the solar radiation is getting a more vital importance, especially in the drying of agriculture products. The drying process is a traditional application and very widely used product preservation. At the same time, the quality control and quality preservation also become essential technologies for processing of agricultural products than before. Solar drying technology has many features upon the traditional drying techniques as it is a low-cost process and clean. In the past, the agricultural and other products have been dried by the direct sun and wind in the open air for thousands of years. A typical solar dryer improves upon the simple open-air sun system in many main features:

- Products can be dried in a shorter period than the simple operations. Solar dryers improve drying process time by two methods. First, by enhancing the translucent cover the glass cover over the heat collection area inside the solar collector raising the temperature of the air and improving absorber plate surface by increasing heat transfer area. Secondly, the flexibility of adjusting the solar collection area allows for more amount of the solar radiation income.

- Solar dryers are more efficient than open-air sun systems. The possibility of products losses will be less immediately after harvest season. That is especially for products, which require immediate drying such as fresh grain with high initial moisture content.
- The control features of the drying process variables such as air temperatures, air humidity, air flow velocity, and product moisture content are much better than in the case of open-air sun dryers.

According to the past literature, there are many classification methods for dryers generally and solar dryers especially. The most traditional classification depends on the heating modes, air movement inside the dryer and the structure of these systems. They can be classified into two major groups as shown in Figure 1.

Othieno^[1] explained most straightforward solar cabinet dryer, it was a simple structure, and consists mainly of a small box has been made from wood. A transparent glass sheet was used as cover at upper edges surface. The box sides and bottom surfaces can be constructed from a metal sheet (aluminum) or wood. For air circulation through the system, many holes have been made on the sides of the dryer for this purpose. Indirect solar dryers also made of wood and plywood as presented by Amouzou et al.^[2]

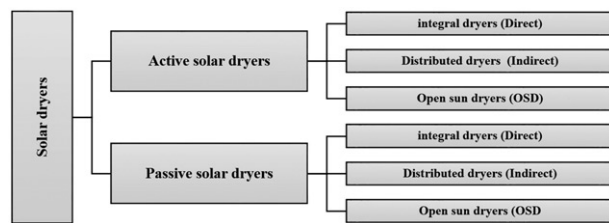


Figure 1. Classification of solar drying systems.

10–15 kg of the product can be dried by drying chamber in 3 days. The absorber plate for the solar collector is made of galvanized sheet metal painted black to get a selective surface.

Simate^[3] presented a comparison of optimized mixed-mode and indirect-mode with natural convection solar dryers for maize. The two solar drying simulation models were validated against results from a laboratory solar dryer with experiments carried out under a solar simulator at the University of Newcastle, UK. They reported that in both types, the collector and dryer width are the same. Buoyancy force drives airflow in the system. The drying cost was 12.76 \$/ton in case of the mixed-mode dryer system, which was about 26% less than using the indirect-mode system. The quantity of dry grain obtained from the mixed-mode dryer for the 1-year period was approximately 2.81 tones and was less than that from the indirect mode dryer by 15%.

According to the investigations under controlled conditions of many drying experiments, a mixed-mode dryer with forced convection was constructed by Pardhil and Bhagoria.^[4] They compared the performance of the smooth and the roughed absorber plate collectors. The thermal efficiency of flat plate solar collector was found to be low because of low convective heat transfer from the absorber plate to the air stream. To enhance the heat transfer coefficient many artificial rib roughness on the absorber plate has been found. The maximum air temperature inside the dryer cabinet was 64.1 °C. In total 3 kg of grapes have been put inside the dryer with having an initial moisture content of 81.4%, and the final moisture content was about 18.6% and achieved within four days while it was eight days for open sun drying. This laboratory device was constructed to have a maximum collector absorber plate area of 1.03 m². This solar dryer system has been used in many experimental tests under different conditions. Halewadimath et al.^[5] studied and fabricated an indirect forced-natural convection solar air dryer to estimate its performance under dry and hot weather conditions of Hubli, Karnataka, India. The system has been tested experimentally for both natural and forced convections. The

performances of two different convection systems were compared. The system was constructed of solar flat plate collector, drying chamber, and a chimney. There were six baffles (fins) attached to the absorber plate to increase the turbulence of flow and increase heat transfer area for heated air in the collector.

Madhlopa et al.^[6] studied a solar dryer system having composite absorber plate on the principles of psychometrics. The dryer consists of a flat plate solar collector, absorber plate approved with wire mesh, glass cover, chimney and insulated drying chamber. The drying chamber and solar collector box were made from wood sheets. The solar collector was connected to a drying chamber for product dehumidification. Additionally, a mathematical model was developed by Ramos et al.^[7] to simulate solar drying of grapes. The heat and mass transfer models were solved by an explicit finite differences method by considering changing boundary conditions. Many experiments were performed on a mixed mode solar dryer located in the North of Portugal, with amount pre-blanched grapes. Simulations showed with the developed model can be good to estimate accurate drying times and then design, control and optimize the production of different foods.

According to the brief review for many kinds of literature, it can be stated that the performance of solar drying process depends mainly on the performance of solar air collector. The improvement of solar air collector will improve the dryer work also. At the same time, the control of the process variables as air temperature, humidity, velocity and the moisture content for products to be dried are essentially important.

In the recent paper, thermal performance analysis of two types of solar collectors was investigated. The first is working with horizontal finned absorbing surface and the second one with the vertical-finned absorbing surface. The final goal was to estimate the drying time in a forced convection solar dryer by using the two mentioned collectors under the same working conditions and weather. In the experiments, a sliced apple was used as a test material.

Drying system analysis

In this article, a study is focused on a representative convective solar dryer (distributed solar dryer with forced convection). The test rig is constituted of two main parts. The first part is a two air pass solar collector which composed of the flat copper plate used as an absorber surface, covered from the above by a glass sheet, which was fixed on the upper edges of collector

box, and collector box that insulated from all sides to decrease heat losses. The second part is the drying chamber made with the support of five trays where the product is put. Drying chamber has been insulated to minimize the thermal losses to the surrounding. As mentioned, the study was by forced convection, the movement of air was by an external force with using an inline air blower which connected to power supply.

The drying system is energized by the sun's rays (solar radiation energy) passing through the collector glazing cover. The trapping of the solar radiation (short waves) is enhanced by the inside surfaces of the solar collector that were painted black to change it to heat energy (long waves). Then, the heat energy will transfer from the black absorber plate to the air, which passes inside the collector by convection. The air will flow through the drying chamber by the effect of the inline blower which is installed in the air duct. Energy exchange (heat and mass transfer) between products items and hot air occurs inside the dryer chamber. The moist and hot air rises and escapes from the upper vent in the drying chamber while cold air at ambient temperature enters through the lower vent in the solar collector.

When drying chamber is empty (no products items), the inlet relative humidity of air is higher than its value at the exit because of the exit air temperature is higher than its value at the inlet. So, the sensible heated air has the ability to catch more water content than the cold air as a result of density difference.^[8]

For the flat-plate solar collector, it is always tilted in such a way that it receives maximum solar radiation during the day, and to be perpendicular to solar radiation rays at noon. Based on Duffie and Beckman,^[9] the best stationary orientation is due south in the northern hemisphere and due north in the southern hemisphere. Therefore, solar collector in this work is oriented facing south and tilted at 45° to the horizontal according to the solar chart for Budapest region (Budapest 47.5° N, 19.05° E) as represented in Figure 2.

Specifications and analysis of solar collector

The solar collector has a total area of 120×50 cm length and width respectively. A copper sheet with a thickness of 1.5 mm is fixed as absorbing surface area to change the form of radiation waves to heat energy. To achieve the goals of this study, rectangular fins are integrated with the absorbing surface to increase the area of heat transfer. The attached fins are put in two different directions: horizontal and vertical (Figure 3). The absorbers with fins are painted with matt black in



Figure 2. Installation of solar drying system.

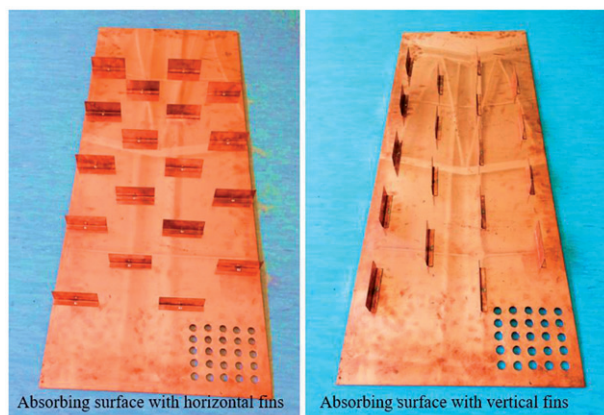


Figure 3. Directions of fins on the absorbing surfaces of collectors.

order to decrease the reflection losses from collector to the surrounding. It has a transparent glass cover attached to the top edges of the collector box. The transparent cover made from high quality hard thermal plastic glass with 4 mm and $0.16 \text{ W/m}^2\text{K}$ thickness and heat transfer coefficient, respectively. Cover dimensions are 120×50 cm length and width, respectively. Its resistance to breakage is about ten times higher than the regular glass of the same thickness. At the back side of the collector, sheets of expanded

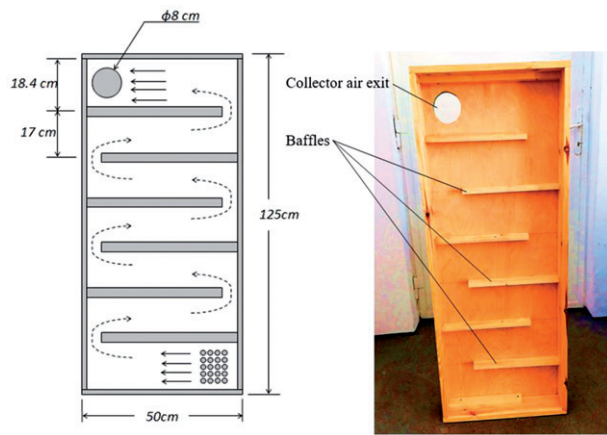


Figure 4. Second-pass design of solar air collector.

polystyrene insulation (EPS) with smooth edges fixed at the bottom base side of the wooden box. The heat transfer coefficient of back insulation is $0.036 \text{ W/m}^2\text{K}$. Wood makes the body frame, covers and the baffles material for many important reasons that were taken into account; which are lighter in weight rather than using metal, the low cost, easy to form and can be considered as insulation especially at shallow temperatures. Many holes are made on the absorber to allow air streams pass from the upper channel to the lower channel of the solar collector. Wooden zigzag baffles are attached in the lower channel in order to give more homogenous air distribution under absorber surface (Figure 4). As mentioned, the solar collector in this work is oriented facing south line and tilted at 45° to the horizontal according to the solar chart for Budapest region. To get more amounts of solar radiation and to reduce radiation reflection, absorber plate painted with matt black color. The energy balance on the absorber plate is obtained by equating the total radiation gained from the sun rays through the glass cover with transmittance (τ) to the total heat loosed from the absorber plate of the solar collector. Therefore,

Solar radiation per unit area = useful heat + heat losses + reflected losses.

If τ is the transmittance of the top glazing cover sheet, I is the total solar radiation incident on the top surface of the solar collector, and A_c is the area of absorber plate, then mathematically the solar radiation per unit area will be:

$$\text{Solar radiation per unit area} = \tau I A_c.$$

The total (global) solar radiation represented by the direct beam, diffuse and ground reflected radiation components. Experimentally, it can be measured by the calibrated solar power meter. Theoretically, it can be estimated according to the location (Gödöllő) and the time. The direct radiation component on the

collector surface can be calculated according to ASHRAE 2005 standard.^[10] The diffuse (indirect) and ground reflected solar radiations can be estimated according to Al-Joboory.^[11] The mathematical formulation for reflected energy losses from the absorber surface is given by the following expression:

$$\text{Reflected losses} = \rho \tau I A_c,$$

where; ρ is the reflection coefficient of the absorber surface plate. By the substitution the terms of solar radiation and reflected losses in the general energy balance equation, for the absorber plate will get:

$$\tau I A_c = \text{useful heat} + \text{heat losses} + \rho \tau I A_c$$

By rewriting the above relation:

$$\text{Useful heat} = \tau I A_c(1 - \rho) - \text{heat losses}.$$

For an absorber plate, according to Duffie and Beckmen,^[9] $(1 - \rho)$ equals (α) . Then:

$$\text{Useful heat} = (\alpha \tau) I A_c - \text{heat losses}.$$

The above expression represents the energy balance equation for the absorber plate surface. For this study, it is very important to estimate air temperature rise through the collector. The change of air temperature depends on how much energy absorbed (collected) by the absorber plate. So the above energy balance is not sufficiently enough to describe the behavior of air temperature distribution.

In the direction of the air stream, the ambient inlet air to the collector carried sensible heat energy also depends on its mass m^o and temperature $T_{c,i}$. The same for the outlet air, it will catch the heat from stored absorber plate energy by convection, then it will leave the solar collector with the same mass flow rate and new temperature equals to $T_{c,o}$. Then, by considering the heat energy content of inlet and outlet air, the final energy balance for the air solar collector system will be:

$$\begin{aligned} \text{Useful heat} &= (\alpha \tau) I A_c - \text{heat losses} \\ &+ \text{inlet air heat content} \\ &- \text{outlet air heat content.} \end{aligned}$$

Mathematically:

$$\begin{aligned} M c_p \frac{dT_{c,o}}{dt} &= (\alpha \tau) I A_c - U A_c (T_c - T_a) \\ &+ m^o c_p T_{c,i} - m^o c_p T_{c,o}. \end{aligned} \quad (1)$$

Then by rewriting Equation (1), get:

$$\begin{aligned} \frac{dT_{c,o}}{dt} &= \frac{1}{M c_p} [(\alpha \tau) I A_c - U A_c (T_c - T_a) \\ &+ m^o c_p T_{c,i} - m^o c_p T_{c,o}], \end{aligned} \quad (2)$$

where M is the mass of air inside collector duct in (kg), T_a is the temperature of ambient air in (K), T_c is the average temperature of the absorber plate in (K), c_p is an air specific heat at constant pressure in (J/kg K), $(\tau\alpha)$ is called transmittance-absorptance product for glazed collector, and it was for black color absorber plate about 0.87 according to Anderson et al.^[12] and U represents to the total energy losses from the flat plate solar collector.

According to Equation (2), the performance of solar collector depends on exit temperature and thermal losses. In the experiments of this study, inlet, exit, ambient, and average absorber temperatures are measured by using digital thermometer connected with K-type of thermocouples. Solar radiation is measured by using solar power meter at the same inclination as solar collectors. From gained experimental data, useful energy Q_u and thermal efficiency η are calculated according to the Equations (3) and (4):

$$Q_u = c_p m^o (T_{c,i} - T_{c,o}). \quad (3)$$

The thermal efficiency of two solar collectors represents the ratio between useful heat energy, which obtained from Equation (3) to the solar radiation per unit area of absorbing surface A_c as following:

$$\eta = Q_u / (I A_c). \quad (4)$$

Air flow rate m^o calculated by multiplying air density ρ , the area of air flow duct A_d and airspeed v , which were measured by the digital anemometer, and shown in Equation (5):

$$m^o = \rho v A_d. \quad (5)$$

The usual trapezoidal integration method has been used to calculate the amount of daily solar radiation and useful hourly energy that this flat plate solar air collector can afford, which can be defined as follows:^[13]

$$\int_{x_o}^{x_n} f(x) dx = \frac{h}{2} (y_o + 2y_1 + 2y_2 + \dots + y_n), \quad (6)$$

where h represents the time increments, y is useful heat energy at time t and y_o and y_n are initial and final useful heat energy values of the experiment.

Drying chamber analysis

The drying chamber (the dryer) with five trays for the different products items is made from polystyrene blocks. The drying cabin dimensions are $50 \times 50 \times 100$ cm length, width, and height, respectively (Figure 5). Dryer walls have been made from

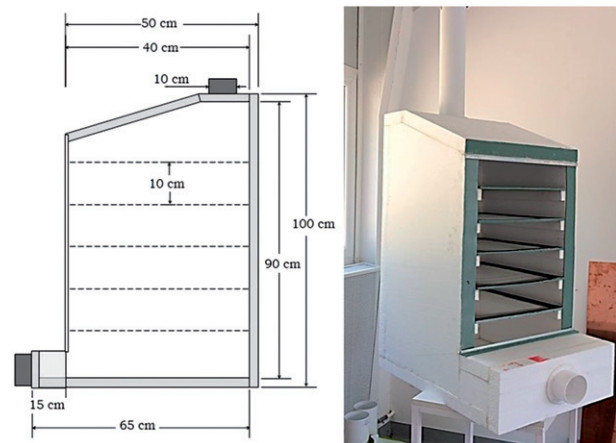


Figure 5. Design of drying chamber.

polystyrene with 5-cm thickness and thermal conductivity 73 W/m K , except the front wall of the chamber made from 4-mm plastic glass sheet for observing. The five trays made from plastic nets and fixed with 10 cm distance between them. The chamber is integrated with the solar collector by a small duct (indirect drying), then the exit heated air from the collector enters the chamber with high temperature and low humidity.

The total energy required for drying process for given quantity of any products items can be determined by using the basic energy balance equation for the evaporation of water. Chamber's basic energy balance equation (mass + heat) is:

$$Q_{\text{air,inlet}} + Q_{\text{product,inlet}} = Q_{\text{air,outlet}} + Q_{\text{product,outlet}} + \text{energy losses.}$$

Experimental results

This part shows the experimental results which gained from drying system. Two sets of results are collected in this section to achieve the objectives of this study. The first set shows the experimental results of horizontal-finned solar air heater test. The second set shows the experimental results of vertical-finned solar air heater test. The air speed for the experiments is 2.3 m/s with air duct cross-section area 0.00635 m^2 . Properties of air which considered for performance calculations are 1.2 kg/m^3 and 1000 J/kg K density and specific heat at constant pressure, respectively. The system tested on 12 October 2017 for 5 h. The results gained under low wind speed and almost clear climate (with some clouds). Wind speed in the day of experiments was about 1.5 m/s .

The temperatures, air flow, and global radiation were measured to calculate the efficiency and analyze

the performance of the solar collector. The temperatures at different points of solar air heater need to be measured to achieve the temperature distribution. For this purpose, the K type twisted thermocouples wire were used, as they are the most widely applied temperature sensors. All the thermocouples have soldered, calibrated and tested before installing. The thermocouples are connected to a digital thermometer.

The global solar radiation is measured by solar power meter with its sensor. It is placed on the same tilt angle of the collector at the same direction. The spectral response of solar meter from 400 to 1100 nm and measurement range varies from 1 and 2000 W/m².

One of the main properties that affect the performance of the collector is the air velocity. An MS6252A digital anemometer instrument was used to measure the air velocity then the air mass flow can be calculated by multiplying with the cross-section area and the air outlet density. The measuring range is 0.4–30 m/s.

Temperatures analysis of solar collectors

Figures 6 and 7 show the variation of ambient (T_a), average absorber ($T_{s,av}$), inlet ($T_{c1,i}$), second pass inlet ($T_{c2,i}$) and outlet ($T_{c,o}$) temperatures of horizontal and vertical double-pass solar air collectors for 5 h of 12 October 2017. At the beginning of the experiment, the temperature difference was very small up to low solar

radiation intensity and low ambient temperature. The highest values of collector temperature differences for the two collectors was reached between 11:40 and 12:40. The highest temperature difference for horizontal and vertical solar collectors were 21.8 and 18.7 °C at 12:30 and 12:10, respectively, while the highest solar radiation intensity was about 1018 W/m² at 12:20. Fins increased the area of the absorber, and it works as an air buffer. For each, the method of fins arrangement (direction) had not sufficient effects on temperature curves shape. In another hand, the exit temperatures of horizontal-finned collector were higher than a vertical-finned collector. The horizontal fins allow the air to still more time in collector duct, that results in increasing heat transfer. The other function of horizontal fins is to trouble air movement streams, that increases the friction forces between air and absorber.

Useful heat analysis of solar collectors

Figures 8 and 9 show the useful gained heat power curves for horizontal and vertical-finned solar air collectors and radiation intensity per unit area during 5 h. Upper and lower air pass useful heat are showed. The effects of fins direction are sufficient, where the value of gained heat power in horizontal-finned collector reaches more than 400 W compared with

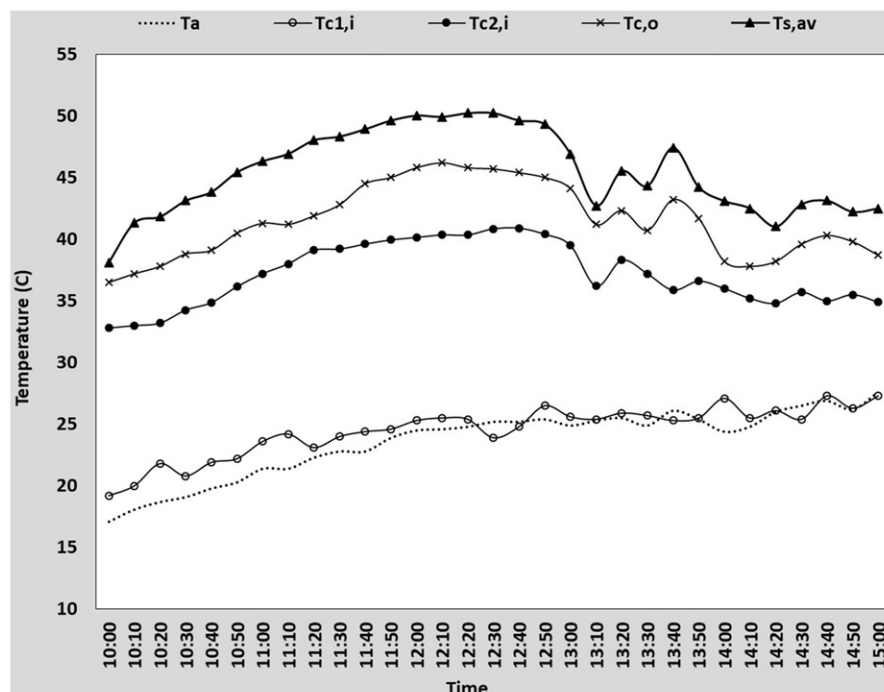


Figure 6. Temperature distribution of horizontal-finned solar collector.

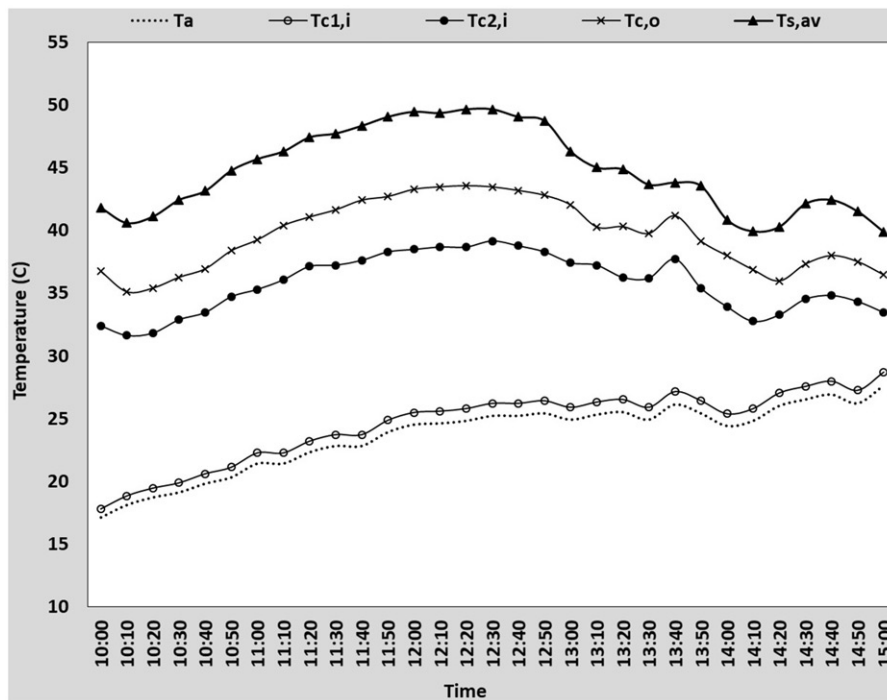


Figure 7. Temperature distribution of vertical-finned solar collector.

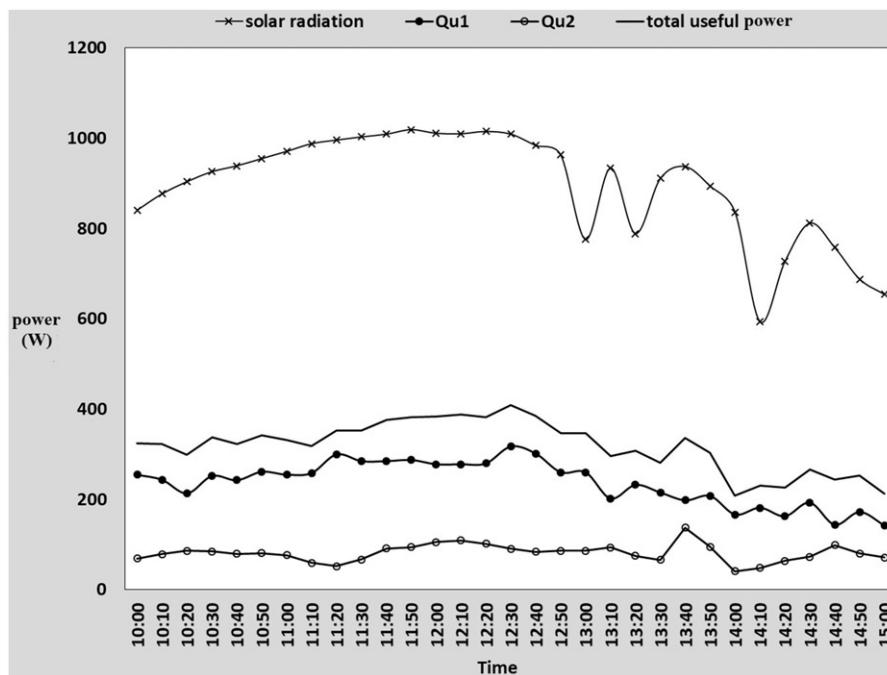


Figure 8. Useful heat power of horizontal-finned solar collector.

vertical-finned air collector with about 327 W maximum useful heat power. The increasing of the absorbing surface area plays the main factor to increase solar collector performance. As explained before, also the turbulence flow of air will cause more friction forces. The solar radiation blocked by some sporadic clouds between 12:40 and 14:20. The effects of solar radiation instability were obvious on

the performance of solar collectors at the end of experiments.

Drying chamber temperature and relative humidity analysis

Figures 10 and 11 show the variations of temperatures inside the drying chamber for the five trays by using

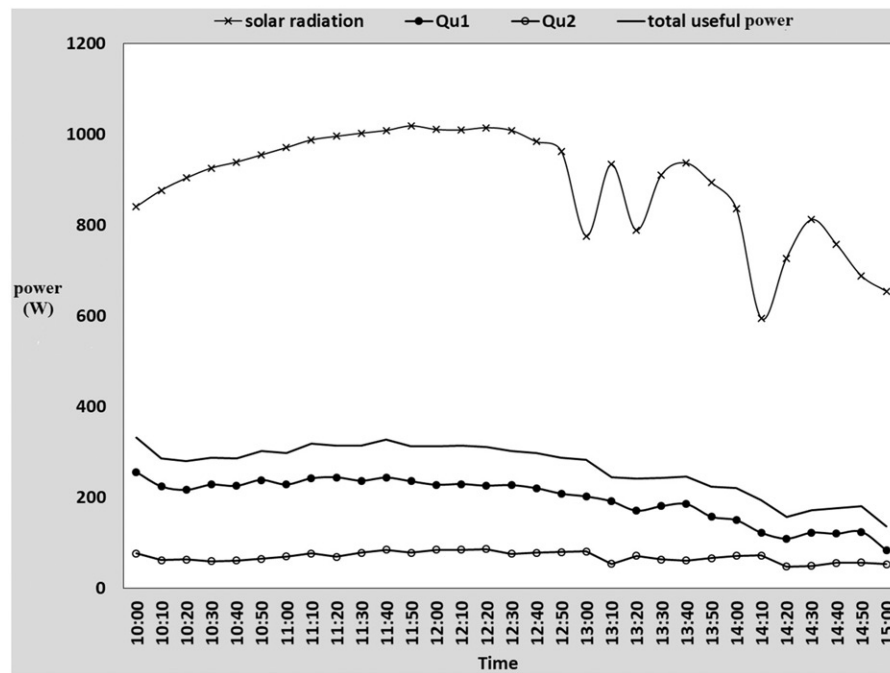


Figure 9. Useful heat power of vertical-finned solar collector.

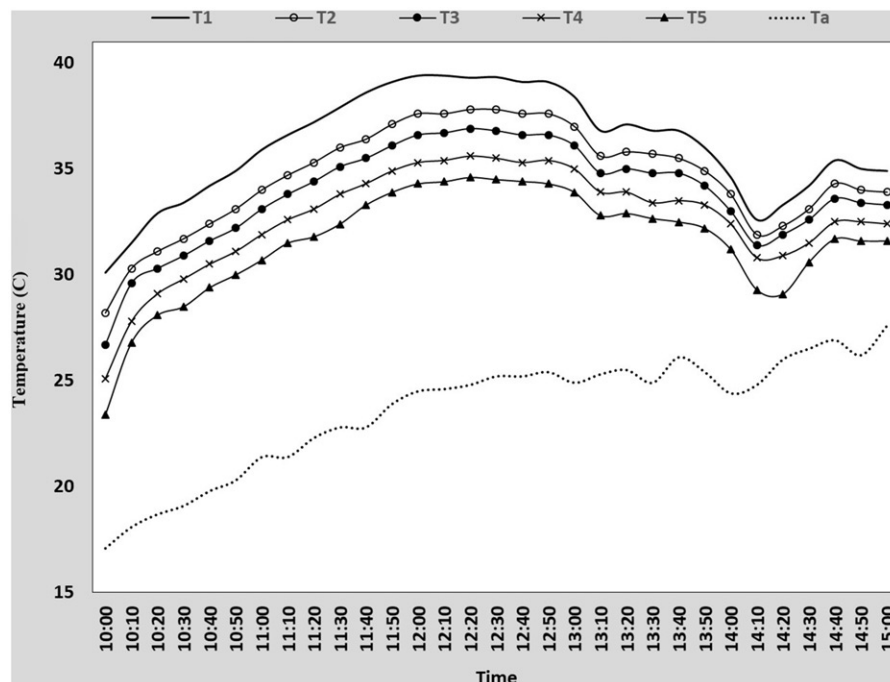


Figure 10. Temperature of drying chamber trays using horizontal-finned solar collector.

horizontal and vertical-finned collectors respectively. As shown, the stratification of temperatures in Figure 10 more clear than Figure 11. The shapes of all curves are hardly affected by the curve of solar radiation in Figures 9 and 8. The temperature difference in the first two trays (1 and 2) is higher than the difference in the last two trays (4 and 5), because the

capacity of air to catch more heat decreases. The process inside drying chamber is a combination of heat and mass transfer (sensible and latent). The sensible heat of air which gained from solar collectors changes to latent heat in term of water content.

From another side, the water content of the air was increased as shown in Figures 12 and 13. The dried

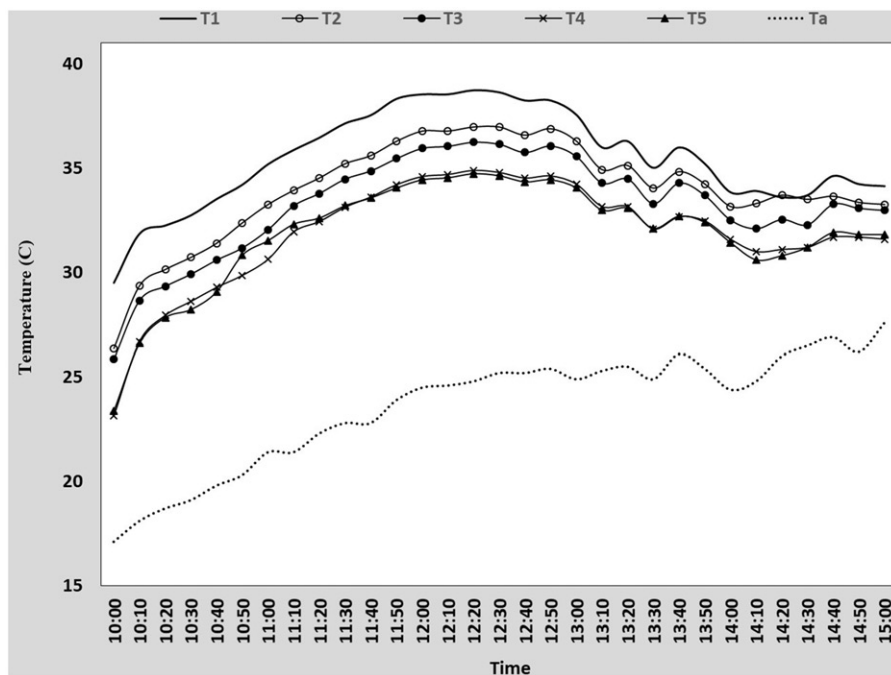


Figure 11. Temperature of drying chamber trays using vertical-finned solar collector.

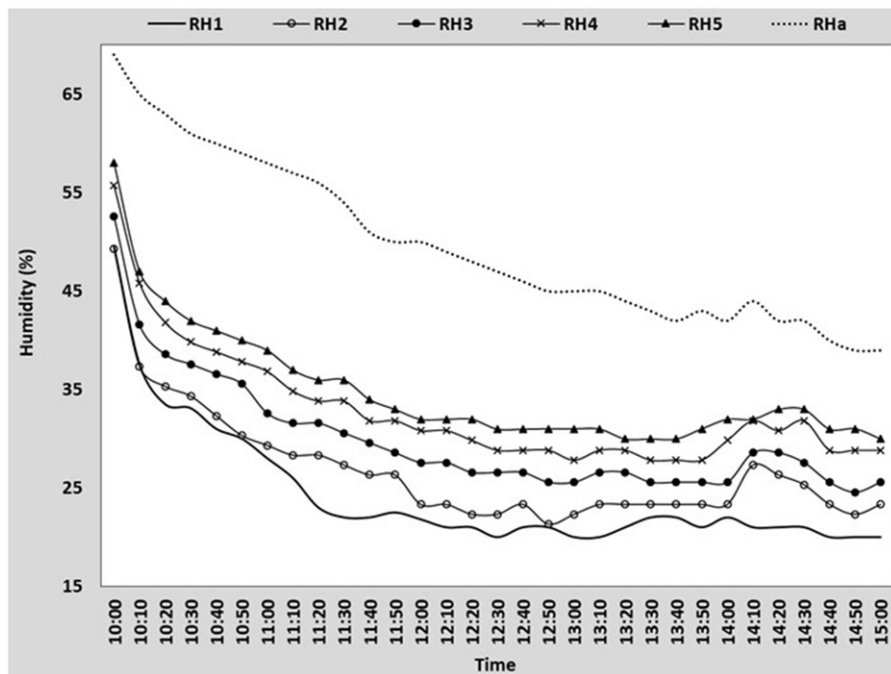


Figure 12. Air humidity of drying chamber trays using horizontal-finned solar collector.

product (apple) missed its water content in the low moist air. In the first two trays of dryer (RH1 and RH2) the relative humidity difference very high compared with the last two trays (RH4 and RH5). At the beginning of drying process, the entered air can catch a large amount of moisture. At the first hour of the experiment, the entered air has high relative humidity

because of the relative humidity of ambient higher in the morning. According to humidity curves, the drying process is not efficient in the morning or at the high relative humidity locations.

Sigge et al.^[14] concluded that drying periods are sufficiently affected by temperature and relative humidity of the air. The increasing of drying temperature at a

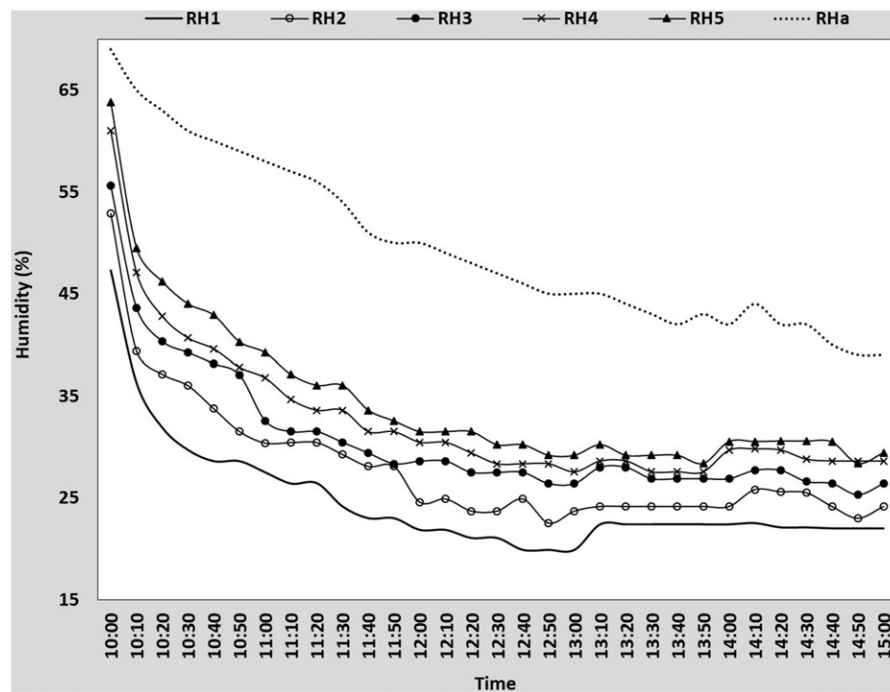


Figure 13. Air humidity of drying chamber trays using vertical-finned solar collector.

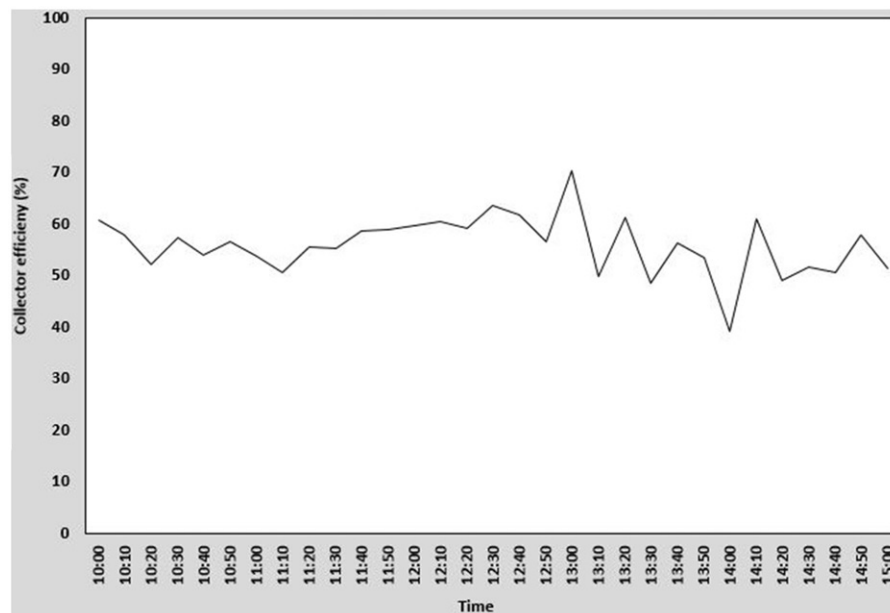


Figure 14. The instantaneous thermal efficiency of horizontal-finned solar collector.

constant RH results in decreasing drying times, while increasing RH at a constant temperature result increased drying times. Drying rates are generally higher at elevated drying temperature with constant RH, and lower at higher RH at constant temperature.

Daily efficiencies and final weight of product

The final performance between horizontal- and vertical-finned double-pass solar air collectors were

compared in form of total instantaneous and daily thermal efficiency. The instantaneous thermal efficiency of horizontal- and vertical-finned solar collectors are presented in Figures 14 and 15, respectively. To predict total the daily thermal efficiency an integration method has been used with time interval of 10 min for instantaneous efficiencies values. The daily solar radiation and useful heat gained from vertical and horizontal-finned collectors were calculated by applying Equation (6) for the curves in Figures 8 and 9 as following:

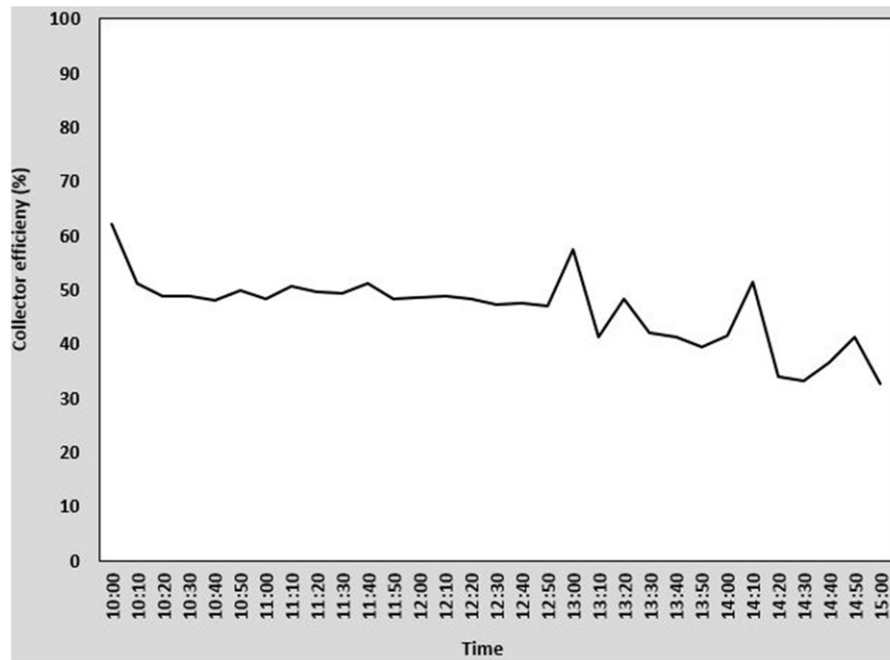


Figure 15. The instantaneous thermal efficiency of vertical-finned solar collector.

$$\begin{aligned}
 Q_{u, \text{hor}} &= \frac{10 \times 60}{2} (323.8 + (2 \times 322) \\
 &+ \dots + \\
 &(2 \times 252.7) + 213.4) = 6746.8 \text{ kJ}, \\
 Q_{u, \text{ver}} &= \frac{10 \times 60}{2} (332.4 + (2 \times 285.5) \\
 &+ \dots + \\
 &(2 \times 180.2) + 136) = 5603.27 \text{ kJ}, \\
 I_T &= \frac{10 \times 60}{2} (840.7 + (2 \times 876.2) \\
 &+ \dots + \\
 &(2 \times 687.2) + 653.6) = 16184.87 \text{ kJ}.
 \end{aligned}$$

To estimate the daily efficiencies of solar collectors, Equation (4) was applied. The total absorbing surface A_c is the summation of the absorber (1.2×0.5) plus eighteen fins area with dimensions $(2 \times 0.1 \times 0.04)$. At the same conditions and solar radiation intensity, the daily efficiency increased by about 10% by changing the direction of integrated fins from vertical (46.53%) to horizontal (56.03%) as following:



Figure 16. The product after and before drying process.

$$\begin{aligned}
 \eta_{\text{hor}} &= \frac{6746.8}{(16184.8 \times 1.2 \times 0.5 (18 \times 2 \times 0.1 \times 0.04))} \\
 &\times 100\% = 56.03\%, \\
 \eta_{\text{ver}} &= \frac{5603.27}{(16184.8 \times 1.2 \times 0.5 (18 \times 2 \times 0.1 \times 0.04))} \\
 &\times 100\% = 46.53\%.
 \end{aligned}$$

The instantaneous efficiencies of horizontal- and vertical-finned solar collectors over experiments time are shown graphically in Figures 14 and 15.

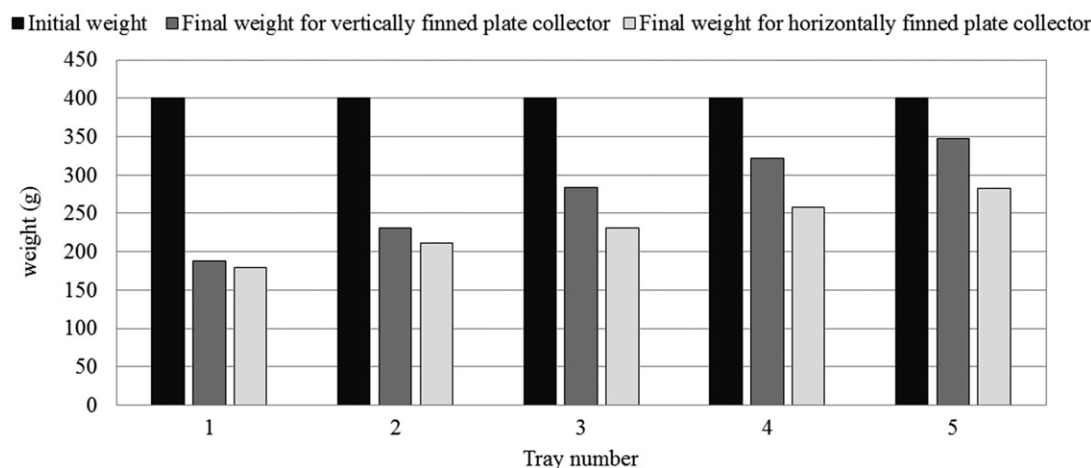


Figure 17. The initial and final weights of apple slices with using vertical- and horizontal-finned collectors.

The mentioned two finned solar collectors were compared with a standard one which was studied by Al-Neama and Farkas.^[15] The collector had the same dimensions and components with a single air pass circulation and unfinned absorbing surface. They obtained that the daily efficiency of solar collector was 43.16% in that case.

The effect of solar collector improvement was obvious at the time of water content losing for the dried product (Figure 16). At the beginning of the test, 2 kg of apple slices are put on drying chamber shelves with average initial moisture content 80%. The slices have approximately the same thickness. After 5 h of drying, the final weights were 1.16 and 1.37 kg by using horizontal- and vertical-finned solar air collectors.

The final moisture contents for apple were approximately 40 and 47% for horizontal and vertical solar collectors, respectively. The final moisture content showed a good agreement for the short time of test (5 h) and compared with 24% as a desired final moisture contents for apple.^[16]

The initial weight for every shelf was 400 g of apple slices. The average diameter of slices was 65 mm with 4 mm as average thickness. The experimental measured final weights for apple slices for all shelves (1–5) are obtained in Figure 17. In the first two shelves, the dried items are lost about 50% of the initial weight for each (horizontal and vertical). In the upper shelves, drying rate is less because the higher air relative humidity.

Conclusions

An experimental study has been carried out to investigate the performance of different directions finned solar collectors for drying processes objectives for the case of apple. The positive influence of the horizontal

fins direction are clearly clarified. The conclusions can be summarized as follows:

1. The outlet temperature of the horizontal-finned solar collector was higher than in the case of vertical-finned solar collector.
2. The effects of fins direction are sufficient, where the value of gained instantaneous heat power in horizontal-finned collector reaches more than 400 W, while reached about 327 W by vertical-finned air collector.
3. The temperature and relative humidity difference in the first two trays of drying chamber (1 and 2) is higher than the difference in the last two trays (4 and 5).
4. By changing the direction of integrated fins from vertical to horizontal direction, the daily thermal efficiency has increased by about 10%.
5. After 5 h drying of 2 kg apple slices drying, the final weights were 1.16 and 1.37 kg by using horizontal- and vertical-finned solar air collectors, respectively. The drying process by using the horizontal-finned solar air collector is faster than vertical-finned solar air collector under the same conditions.

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