Performance Enhancement of Natural Convection Indirect Solar Dryer by Integrating Reflectors

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ABSTRACT

Natural convection indirect type solar dryer integrated with reflectors that can be used for drying fruits and vegetables was designed, constructed and evaluated. The study mainly tried to improve performance of a prototype natural convection indirect solar dryer. The solar dryer was integrated with reflectors and its thermal performance was experimentally analyzed and results were compared with the same dryer without reflectors. The experiments conducted included no load test to determine the stagnation temperature that can be reached and drying tests using tomato slices. During the drying test moisture content at initial and final stages were measured using moisture balance instrument. The mass of the tomato slices was measured every two hours to find the drying efficiency. Temperatures were measured using thermocouples located at the absorber plate and at the trays inside the drying cabinet. Solar radiation was also measured using pyranometer located near the dryer. During no load experiments the maximum temperature reached at the collector was around 98ºC for the dryer without reflectors. The maximum temperature was improved to around 154ºC during the test with reflectors. Similar temperature improvement was obtained during the drying tests as well. Due to the improvement in the temperature in the collector, the drying rate was also improved by 8% for 10 kg and 14% for 5 kg load. The experimental results indicate that the dryer performance was improved when the reflectors were added.

Keywords: Solar dryer, Collector, Reflectors, Vegetables, Moisture, Ethiopia.

1. INTRODUCTION

Fruits and vegetables play an essential role in human nutrition. Apart from providing flavor and variety to human diet, they serve as important sources of vitamins and minerals which will prevent diseases and promotes good health. Most fruits and vegetables contain high percentage of water and therefore are highly perishable. Therefore, preserving fruits and vegetables is necessary to keep them for a long time without further deterioration in their quality in order to utilize their nutritional value efficiently (Dikbasan, 2007).

Various methods of preservation of fruits and vegetables such as drying, controlled atmosphere, canning, dehydration, refrigeration are being used across the world. Drying is a process of moisture removal from a product. It can be achieved by various means like freeze drying, mechanical drying, vacuum drying, thermal drying and chemical drying (Hermann, 2004;

Hawlader et al., 2006; Hawlader et al., 2005; Hailay, 2018). Solar energy is the most attractive and abundant form of renewable energy sources because it is free, environment friendly and available most of the year. The most common and simplest application of solar energy is to convert it into heat. Solar drying, as one type of solar thermal application, is the most attractive method used to preserve fruits and vegetables. It can eliminate wastage, increase the productivity of agricultural, and improve the production of fruits and vegetables in terms of quality and quantity. Studies reported in literature on solar drying attempt to improve the efficiency through optimized design and fabrication (Raju et al., 2013) or by including fan for forced circulation of air (Seveda, 2013). Design and development and prototype of a dryer were carried out previously and test results were reported in Dawit et al. (2015); and Dawit (2013).

The aim of this study was to investigate the performance improvement of an existing natural convection indirect solar dryer by incorporating reflectors. Numerical analysis was carried out to study the effect of side and bottom reflectors in enhancing the amount of radiation reaching the absorber. Based on the numerical analysis the optimum angles to position the reflectors were determined. The analysis and results have been reported in Tabet et al. (2017). Experimental tests were then carried out for both dryer without reflectors and with reflectors.

2. MATERIALS AND METHODS

The dryer mainly consisted of a glass cover, an absorber plate, wooden sides, bottom insulation, drying chamber and chimney. Reflectors were made by attaching solar reflective surface on a sheet metal. The reflective surface was glass film sticker having a thickness of 0.05 mm and 88%ofreflectivity. The cover glass was a single layer of 4 mm thick glass. The absorber was 1 mm black painted corrugated iron sheet which was enclosed in a casing made from wood in all sides and with 5 cm fiber glass insulation at the bottom. The drying chamber was made from wood and enclosed in casing made from sheet metal. It had three trays– top tray (Tray 1), middle tray (Tray 2) and bottom tray (Tray 3).The trays were made from perforated sheet made from plastic; it was chosen to avoid rusting and contamination of the fruits during drying.

The optimum inclination angles of the reflectors were theoretical determined to get maximum solar radiation that falls on the collector surface. The bottom reflector was kept at 60° throughout the day while the left and right side reflectors were adjusted every two hours. In the experiments fresh tomatoes with initial moisture content of 95% were used. The tomatoes were

sliced about 1.5cm thick and 1 cm wide. Two set of tests were carried out with 5 kg and 10 kg of sliced tomatoes evenly distributed in the three trays. The photographic view of experimental setup is presented in figure 1.
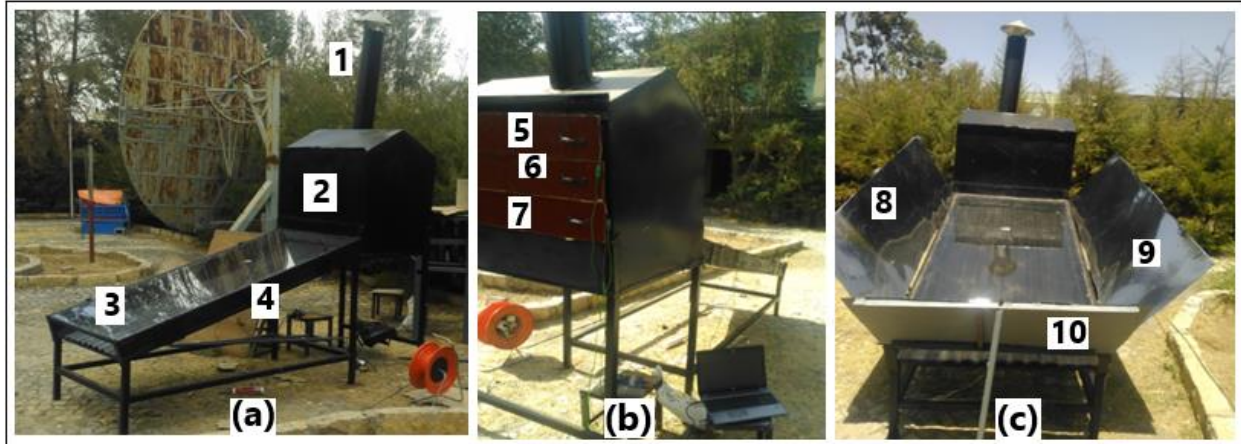

Figure 1. Pictorial view of dryer setup (a) without reflectors, (b) arrangement of trays, and (c) with reflectors (***Note***: 1. Chimney, 2. Drying cabinet, 3. Cover glass, 4. Collector, 5. Tray 1, 6. Tray 2, 7. Tray 3, 8. Right side reflector, 9. Left side reflector, 10. Bottom reflector).

The Estimation of the solar radiation incident on the collector surface was calculated using equation 9.The total solar radiation absorbed by the flat plate solar dryer collector is equal to the sum of direct radiation on the surface of collector I_b, the diffuse radiation by sky I_{ds}, the radiation reflected from the ground I_s. The radiation reflected by the side reflector I_{1r} left towards the collector with an inclined angle γ_1 and, the radiation reflected by the reflector on the right side toward the collector I_{rr} with tilted angle γ_2 and bottom reflector I_{bo} with tilted angle θ_m is given as Tabet et al. (2017).

$$I_T = I_b + I_{ds} + I_s + I_{1r} + I_{rr} + I_{bo} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

The data collection and performance analysis of the dryer were carried out from March to May 2018 at Solar Demonstration Center, Mekelle University (latitude 13.4799^{0}N and longitude 39.4849^{0}E). During this period there was very good solar radiation with mostly clear sky condition.

The thermal efficiency of the collector is defined as the ratio of heat output to the heat input or ratio of energy output to energy input, which is the same as the ratio of the energy addition to the air as it passes through the collector to the energy incident on the collector (Struckmann, 2008).

Collector efficiency, $\eta_c = \dfrac{Q_g}{I_T A_c} = \dfrac{\dot{m} C_p}{A_c I_T}$ … … … … … … … …. … … … … … … … … … … … … … … … (2)

Where,

$\dot{m}$ is mass flow rate of air, kg/s, I_T is insolation on collector surface, W/m^2

ΔT is change in temperature; $^\circ$C,

C_p is air specific heat capacity, J/kg $^\circ$C

Q_g is the useful energy gained,

A_c is collector area, m^2

I_T is the total solar radiation

  (but, for the case of reflectors it is global solar radiation plus reflected radiation from reflector).

The equation below is used to calculate the amount of moisture to be removed from the product, m$_w$, in kg (Dhanushkodi et al., 2014).

$$m_w = \frac{m_i(M_i - M_f)}{100 - M_f}$$ … … … … … … … … … … … … … … … …. … … … … … … … … … … … (3)

Where,

m_i = initial mass of the food item (kg);

M_i = initial moisture content (% dry basis);

M_f = Final moisture content (% dry basis);

Drying rate is the amount of evaporated moisture content over time. To calculate the drying rate the following formula is used (Dhanushkodi et al., 2014).

$$DR = \frac{M_i - M_d}{t}$$ … (4)

Where,

M_i is mass of sample before drying, in kg,

t is drying period, in hrs

M_d is mass of sample after drying, in kg.

The parameters measured during the evaluation of the solar dryer included temperature, mass of tomatoes at each tray, solar radiation and moisture content of the tomatoes at the beginning and end of the tests. The temperature inside the dryer cabinet and collector as well as the ambient temperature were measured by k-type thermocouples. The accuracy of the k-type thermocouple is $\pm 2.2^\circ$C or $\pm 0.75\%$.

The K type thermocouple is connected with Pico Log TC-08 data logger to measure the dry bulb temperature at different locations of the solar collector and drying cabinet during

experiment. A pyranometer of the type METEON irradiation meter was used to measure the global solar radiation. The pyranometer measures the sum of the beam and diffused solar radiation. The total solar radiation in W/m^2 was record by the data logger.

A moisture balance instrument model HB43-S (Mettler Toledo) was used to determine the amount of moisture content in the tomatoes before and after drying. A digital weighing scale model PT-600 was used to weigh the drying tomatoes to determine the weight loss. The initial weight of the tomatoes to be dried was weighed before placing in the dryer. Once the drying started, the tomatoes being dried were taken out from the dryer every two hours for the weight to be measured.

3. RESULTS AND DISCUSSION

3.1. No Load Test

No load tests were carried out in different days where the dryer was set with reflectors (WR) and with no reflectors (NoR). The tests were repeated for three days with each set up to know the variation of temperature at the collector and drying cabinet. Figure 2 shows representative data plot of both type of tests with reflector (WR) and with no reflector (NoR). The solar radiation measured for both days is included in the plot. Similar and very good radiation intensity was observed for both days.

It was observed that during the no reflector test the maximum absorber temperature reached was 98°C and the maximum temperature reached at the tray 2 was 48°C. On the other hand during the test with reflectors the absorber temperature reached 154°C and the tray 2 temperature reached 61°C.
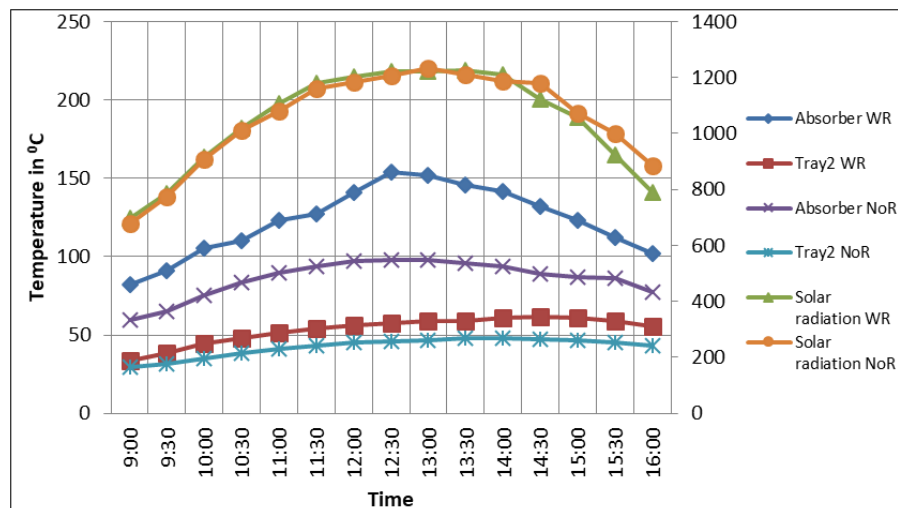

Figure 2. No load test result showing temperature variation with time of the day.

3.2. Drying Test without Reflectors

Figure 3 shows a typical day results of the hourly variation of the temperatures in the solar collector and the drying cabinet during 5 kg load drying without reflectors.
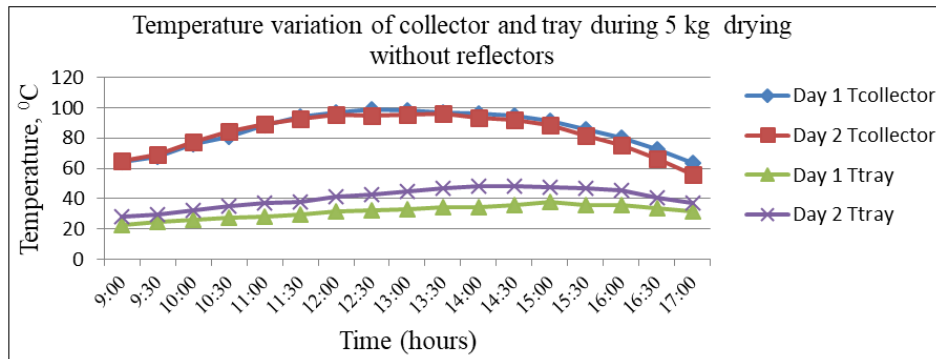

Figure 3.Temperature variation with time, 5 kg loadwithout reflectors.

From the graph it can be observed that the maximum collector temperature reached in the mid-day for day 1 and day 2 were 99ºC and 95ºC respectively. Average daily temperature inside cabin was around 34ºC and 38ºC whereas maximum temperature inside the cabinet for two days was up to 37.7ºC and 48.4ºC. The observed rate of evaporation was higher in the first day compared with second day due to presence of high inherent moisture content.

Figure 4 shows a typical day results of the hourly variation of the temperatures in the solar collector and the drying cabinet during 10 kg load drying without reflectors.
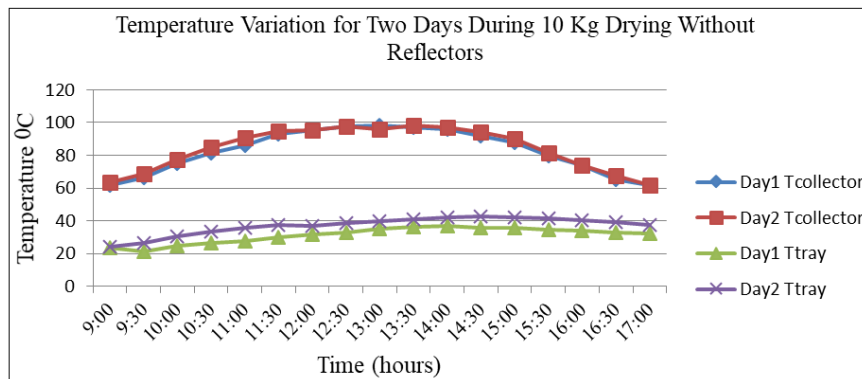

Figure 4.Temperature variation with time 10 kg without reflectors.

From the graph, it can be observed that the daily average temperature for the two days experiment in the drying unit was 32.3ºC and 37.8ºC respectively with loading of 10 kg sliced tomatoes. The maximum temperature reached during the two days test was around 97ºC, while the

temperatures at the tray were 36°C, and 42.5°C for day 1 and day 2, respectively. Maximum temperature reached in the cabinet was less during the first day due to high moisture content in the tomato slices.

3.3. Drying Test with Reflectors

Figure 5 shows a typical day results of the hourly variation of the temperatures in the solar collector and the drying cabinet with reflectors during 5 kg sliced tomato drying. It can be noticed that the maximum collector temperature attained for the ensuing two days was 135.6°C and 127.5°C. For day 1 and day 2 the average daily temperature inside cabinetwas around 41.0°C and 53.8^{0}C and the maximum temperature inside the cabinet was up to 49.7°C and 62.3°C respectively. The temperatures at the absorber during the test days were found to be higher than the tests during the no reflector cases by around 40°C. This result is similar to the no load tests carried out for both no reflector and with reflector cases.
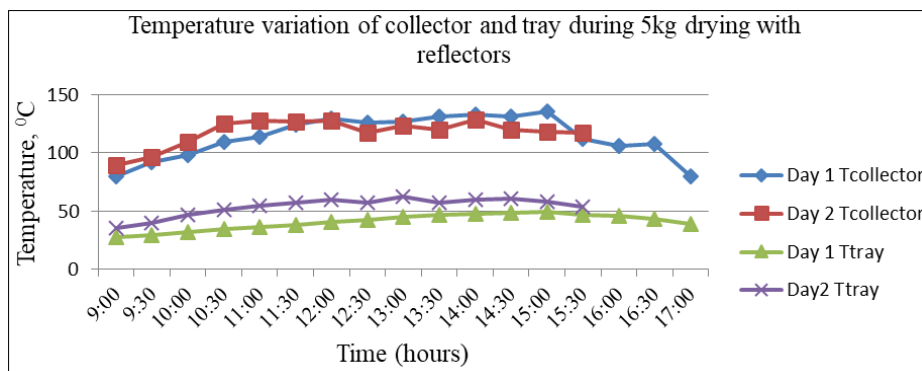

Figure 5. Temperature variation with time, 5 kgwith reflectors.

Figure 6 shows a typical day results of the hourly variation of the temperatures in the solar collector and the drying cabinet with reflectors during 10 kg sliced tomato drying.
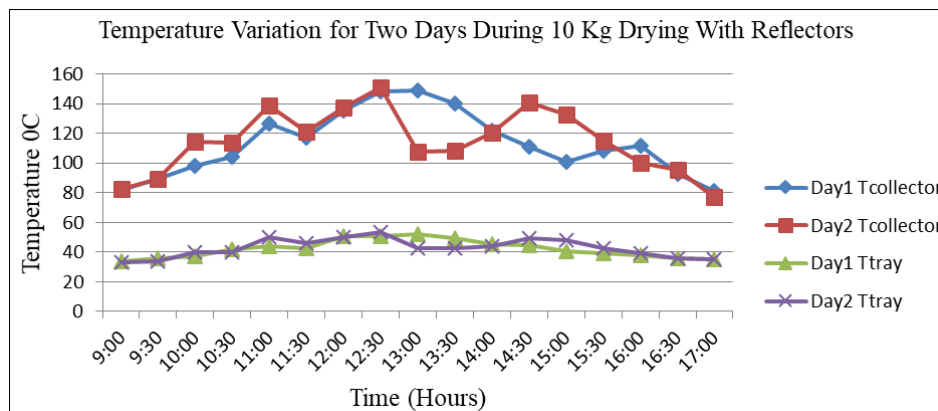

Figure 6.Temperature variation with time, 10 kg with reflectors.

During two days experiment 10kg drying of the solar dryer with reflectors, the daily average temperature in the drying unit was 43.2ºC and 42.8ºC respectively. The maximum temperature reached of the collector and cabinet was 149ºC, 52ºC and 150^{0}C, 53ºC respectively. The maximum temperature reached during the two days test was around 150^{0}C, while, the temperatures at the tray were around 52ºC. It is important to note that in this test on the second day in the period between 13:00 to 14:00 there was problem in the adjustment of the reflectors and hence significant temperature drop was observed.

3.4. Weight Loss Calculations for the Tests without and with Reflectors

To estimate the weight loss, the tomato slices were weighed every two hours using the digital weighing scale and the results are shown in figure 7.
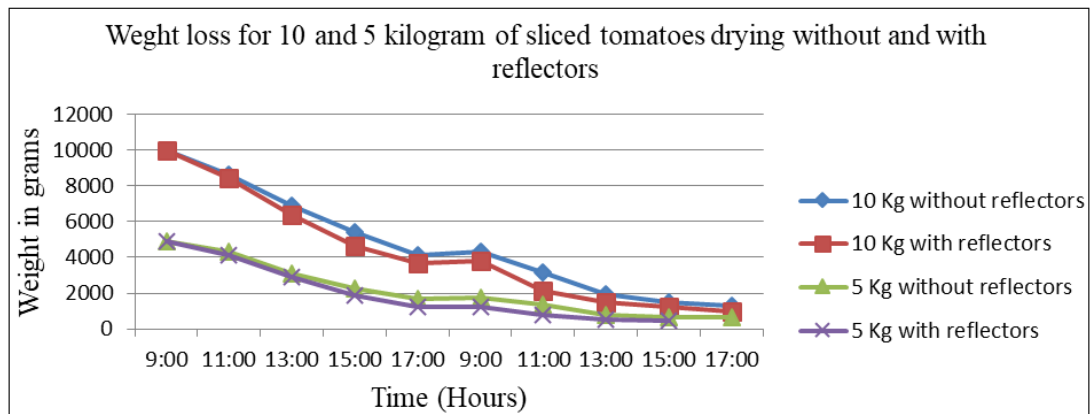

Figure 7.Weight loss of tomato slices for day 1 and 2, with and without reflectors for 10 and 5 kg load.

The weight loss during the first day for the 5 kg without reflectors experiment was 65.6%, whereas for the second day it was 37.1%. The reduction in the weight loss for the two days was found to be 87.2 %. After two days of drying the moisture content reached 12.8% still above the 10% requirement. On the other hand, the weight loss during 5 kg with reflectors experiments was 74.7% and 35.9% for day 1 and day 2, respectively. The reduction in the weight loss for two days was found to be 91 %.In the second day the final required moisture content was attained at 15:00.

Similarly, the drying test for the case of 10 kg tomato without reflectors indicates that the weight loss was 58.5% after one day and reached 88.5% at the end of two days. The moisture content was above 10% after two days of drying. For the case with reflectors the weight loss was 63.4% on the first day and 91.5% at the end of the second day. The required moisture content was attained at the end of two days of drying.

During the experiment, it can be observed that there was increment of weight of the tomatoes at the beginning of the second day compared to the weight at the end of the first day. This is due to moisture re-absorption by the tomatoes during the night.

Figure 8 depicts drying rate for 5 and 10 kg tomato slices with respect to time of the solar dryer without and with reflectors.
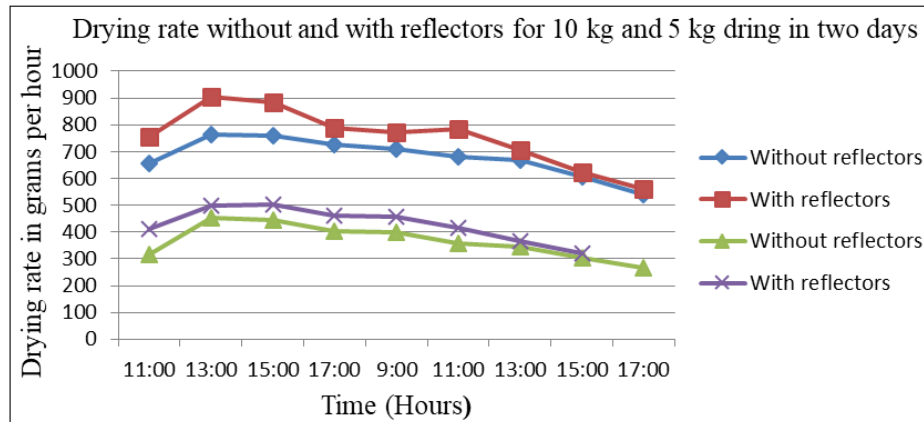
Figure 8. Drying rate of the solar dryer without and with reflectors during the two days drying.

From the graph it was observed that the drying rate for both cases reached the maximum on the first around noon time. The drying rate then decreased beyond noon time and during the second day as well. In the second day, as more moisture is extracted from the tomato, it becomes more difficult to extract further. The daily average drying rate for 5 kg load without and with reflectorswas 403.5 g/h and 459.6 g/h, respectively. While for the 10 kg load the dry rate was found to be 727.8 g/h and 789g/h, respectively. Therefore, there was increase in performance of the dryer due to the addition of reflectors by about 8% for the 10 kg load and about 14% for the 5 kg load.

4. CONCLUSION

Experimental investigation on a solar dryer to improve its performance by adding reflectors was carried out. No load and drying tests were conducted for both without reflector and with reflector cases. During no load test the average maximum collector temperature at the absorber plate without and with reflectors was found to be 98°C and 154°C, respectively. This indicated a significant improvement on the solar dryer due to the addition of reflectors.

During drying experiments with tomato slices, maximum temperatures reached at the absorber plate and inside the cabinet were around 100ºC and around 48ºC for the dryer without reflector. On the other hand, maximum temperatures reached at the absorber plate and inside the cabinet were around 150ºC and around 62ºC for the dryer without reflector. Due to the improvement on the temperature of the collector, the drying performance was increased by 8% for the 10 kg load and by 14% for the 5 kg load case.

5. ACKNOWLEDGEMENTS

7. CONFLICTS OF INTERESTS

The authors declare no conflict of interest.

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