

Comparison of Thermal Performance Between Two Solar Air Collectors for an Indirect Solar Dryer

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ABSTRACT: *The article presents a comparison of the thermal performances between two solar air collectors for an indirect solar dryer. These two collectors were designed and built in the Solar Energy and Environment Laboratory of Mohammed V University, Rabat, Morocco (latitude 34° N and longitude 6°49' W). The absorber of the first collector consists of an alveolar plate made of polyethylene, with the alveolus having a section of 1 cm². The absorber of the second collector consists of two stainless aluminium plates, corrugated and superimposed in opposition to form parallel cylinders, with a diameter of 9 cm. The results show that the corrugated absorber collector offers better thermal performance than a polyethylene plate collector. The average efficiency was found to be 77% under forced convection.*

Keywords: Solar air collector, indirect solar dryer, corrugated absorber, polyethylene plate, thermal efficiency

1. INTRODUCTION

Solar drying is one of the processes used for food preservation. It avoids losses due to excess production. The solar dryers of food generally consist of two essential elements: a drying chamber, where the food to dry is spread out and an air solar collector for heating the air serving as heat transfer fluid which is routed to the drying chamber.

To maintain food nutritional quality, the food is not exposed directly to the sun's rays but dried with the warm air coming from the collector. This is known as indirect drying.¹ It should be noted that the air used as heat transfer fluid has relatively lower physical properties than those of other materials, particularly water. The thermal capacity of the air is four times lower than that of water, thermal conductivity of air is 20 times lower than that of water, and air density is a thousand times smaller. Thus, air is used well as a thermal insulation than a heat conductor. Therefore, particular care must be taken during the design and construction of solar air collectors. Many new techniques have been developed and used. One of them is to change the absorber surface shape. Indeed, the absorber constitutes the sensitive element of the collector; absorber shape and absorber constitution have a direct effect on the efficiency.

Several works around the world have been carried out and have focused on improving the performance of solar air collectors. Njomo studied theoretically the thermal behaviour of a combined plastic-glass flat plate solar air collector.² He deduces that the combined plastic-glass cover air collector shows slightly better thermal performances than the conventional two glass air collector. Li et al. presented a comparative study on the performance of a new solar air collector with different surface shapes: sinusoidal corrugated plate, protrusion plate, sinusoidal corrugated and protrusion plate and a base flat-plate.³ The results show that the changing shape of the absorber plate is better than the flat plate. Gianpiero et al. reviewed the experimental results in flat solar thermal collectors over the past decade.⁴ Esen presented an experimental energy and exergy analysis of a double flow solar air heater having different obstacles on absorber plates.⁵ The results show that adding obstacles ensure a good air flow over and under the absorber plates, create turbulence, and reduce the dead zones in the collector. Choudhury and Garg presented an analysis made on corrugated and flat plate solar air heaters of five different configurations with different air channel lengths and different specific mass flow rates of air.⁶ The results reveal that too large an air velocity and too small an air channel depth lead up to excessive pressure drop in the solar air heater and hence in excessive fan running costs. This factor suggests the existence of air flow channel with optimum dimensions which would correspond to efficient and cost-effective designs of the solar air heaters. Gao et al. conducted a numerical study on the natural convection inside the channel between the fat-plate cover and the sine-wave absorber in a cross-corrugated solar air heater.¹⁰ They found that to remove the natural convection heat loss effectively, A (characteristic height ratio) should be larger than 2, L (geometrical ratio) larger than 1 and θ (angle of inclination of the heater) less than 40° .

Our study deals with the conception and realisation of two solar air collectors adapted to an indirect solar dryer. The absorber of the first collector was made of polyethylene and the second one was fabricated from two corrugated stainless aluminium plates. The evaluation of thermal performance allowed us to select the best collector suitable for the solar dryer.

2. EXPERIMENTAL

The air heated in the solar air collector will be routed to the drying chamber and will be in contact with the food to dry. Thus, this air should not be contaminated or loaded with toxic elements when it gets through the absorber. The material of absorber should reflect this hygienic appearance. Therefore, the polyethylene and stainless aluminium have been chosen as absorber materials.

2.1 Solar Collector with Polyethylene Absorber

The collector consists of an alveolar polyethylene plate. The section of the alveoli has a square shape of 1 cm^2 . These alveoli allow the air to flow a serpentine circuit inside the polyethylene plate as shown in the diagram of Figure 1. An insulating cork plate of 5 cm thick was placed under the aluminium plate, painted in matt black paint. The cover consists of a glass of 6 mm thick and was fixed above the polyethylene plate. The test was carried out with and without ventilation.

The ventilation system includes a ventilator of variable flow until $320\text{ m}^3\text{ h}^{-1}$, linked to a conical pipe in order to duct the air towards the alveolus of the collector.



Air circulation within the polyethylene plate

Figure 1: The solar air collector with polyethylene absorber.

2.2 Solar Collector with Corrugated Aluminium Absorber

The second collector consists of two corrugated aluminium sheets, painted in matt black paint. The two corrugated sheets are superimposed in opposition to form parallel cylinders, with a diameter of 9 cm, allowing air to circulate along the collector. A 6 mm thick glazing was used as cover. A 5 cm thick cork plate was placed under corrugated absorber to minimise heat loss at the bottom of the solar air collector. The test was realised with and without ventilation.



Corrugated aluminum absorber

Figure 2: Solar air collector with corrugated aluminum absorber.

Table 1: Component and dimensions of the two solar air collectors.

Solar air collector	Components of solar air collector	Dimensions
Solar collector with polyethylene absorber	A box made of iron	1 m ²
	A glass	6 mm thick
	An insulating cork plate	5 cm thick
	A polyethylene plate	1 m ²
	Aluminium absorber plate	1 m ²
Solar collector with corrugated aluminium absorber	A box made of iron	1 m ²
	A glass	6 mm thick
	An insulating cork plate	5 cm thick
	Two corrugated aluminium	1 m ²
	A circular opening	47 cm

2.3 Measurement Performed

In order to follow the evolution of temperature in the two solar air collectors, several T type thermocouples were fixed on the absorber of the two solar collectors at different locations. To avoid direct exposure to the sun's rays, these thermocouples were fitted with a sun cover. Through a junction box, these thermocouples are connected to a system for acquiring and storing the data. Furthermore, a weather station allows to measure climate variables and the solar radiation components. By means of an acquisition program which we have established, the step of measurements of the various variables was set at 5 s. The measures were accumulated, averaged and stored at the end of every hour. Verification and a processing of the data file were carried out before its operation.

Seven thermocouples were placed on the solar collector with polyethylene absorber to study the evolution of the temperature of the air along the collector. They were placed as follows: at the collector input; at the collector output; middle 1 to 1/3 of the collector surface; middle 2 to 2/3 of the collector surface; and in the middle of the surface of the absorber.

3. THERMAL PERFORMANCE RESULTS

To evaluate the collector performances, tests were conducted on summer days with good weather conditions. The two solar air collectors were mounted south-facing, inclined at an angle of 34° corresponding to the latitude of Rabat. The comparison between the two collectors was made on different days.

3.1 Solar Air Collector with Polyethylene Absorber

The results obtained from the collectors designed are illustrated in Figures 3 and 4. As can be seen in Figure 3, the air temperature of the two middles of the collector is higher than that of the outlet. The air reaches a temperature of 45°C in the middle one of the collectors. According to those results, we can deduce that the hot air cannot circulate freely until the outlet of the collector. This problem of air circulation inside the collector comes from the serpentine circulation mode and the small section of the alveolus (1 cm^2), which cause the pressure drops at the ducts of the collector. This small section of the alveolus increases the friction of the air on the walls during air movement. With the lower air velocity at the collector input, air movement becomes almost impossible. To avoid this problem, we considered adding a fan to the collector input to propel the air and increase air speed.

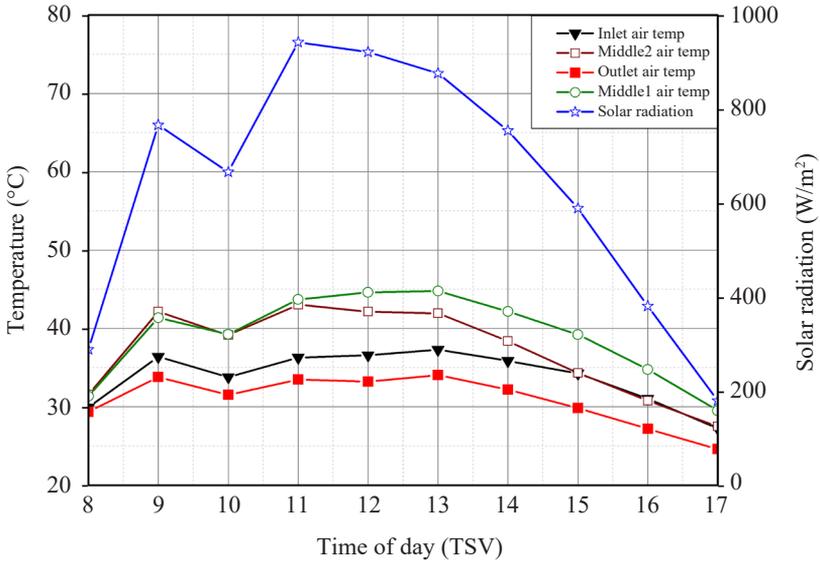


Figure 3: Temperature evolution versus the time for solar air collector with polyethylene absorber under natural convection and hourly measured solar radiation.

As shown in Figure 4, the air temperature in the two middles of the collector is higher than the outlet. It is clear that the use of a fan with a high flow could not improve the thermal performance of the collector. This result can be interpreted by the huge pressure drops at the collector which are proportional to the length of the duct and inversely proportional to duct section. In fact, the serpentine circulation increases the duration of the air stay in the collector to receive the maximum of solar radiation, it introduces increasing pressure drops with the length of the circuit and the too small section of the alveolus stops the circulation of hot air.

These two factors increase the friction of the air on the walls, which prevents air free circulation. Hot air warms and remains stagnated in the collector without reaching the exit. To further improve the thermal performance of our solar air collector, we recommend avoiding the use of serpentine circulation and using direct air pipes with large sections to promote circulation even without the employment of a fan.

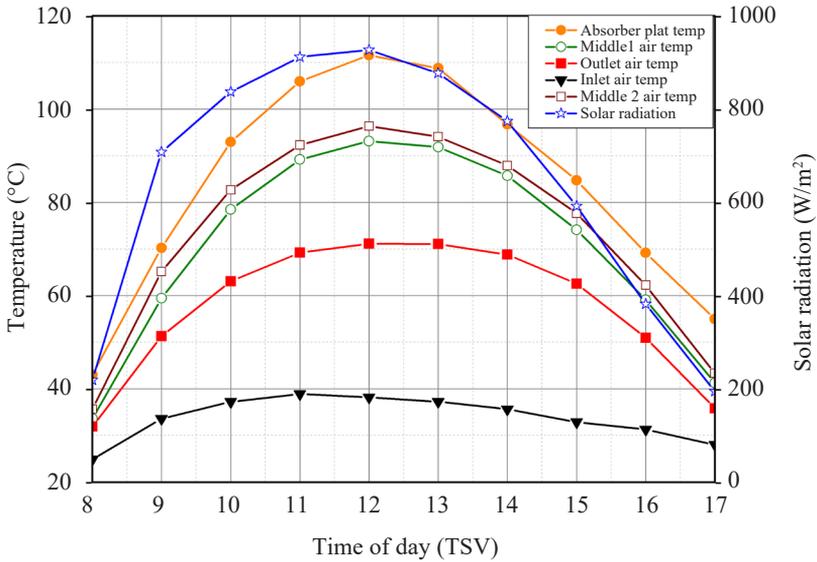


Figure 4: Temperature evolution versus the time for solar air collector with polyethylene absorber under forced convection and hourly measured solar radiation.

3.2 Solar Air Collector with Corrugated Aluminium Absorber

Figure 5 shows the variation of temperature of air at (inlet, outlet) absorber corrugated plate and solar radiation in a clear day of June 2015 under natural convection. The temperature of the absorber is much higher than the other air temperatures at different points of the collector (inlet, outlet). We observe that the temperature difference between the input and the output of the collector is approximately 40°C, for the highest daily solar radiation obtained at 2 pm. The evolution of air temperature at the inlet, outlet and absorber plate during the sunny day of June 2016, under forced convection are presented in Figure 6. The outlet temperature of air decreased for the air mass flow rate of 0.05 kg s⁻¹, to reach a maximum of 35°C at the highest daily solar radiation. The results show that the outlet temperature of air decreased by increasing the air flow rate. Choudhury and Garg reported that the temperature increased by decreasing the air flow rate per unit.⁶ Li et al. noted that the outlet temperature of the air increased for the lowest mass flow rate for the sinusoidal corrugated plate owing to the longer constant times of air with the hot surfaces within the collector.³

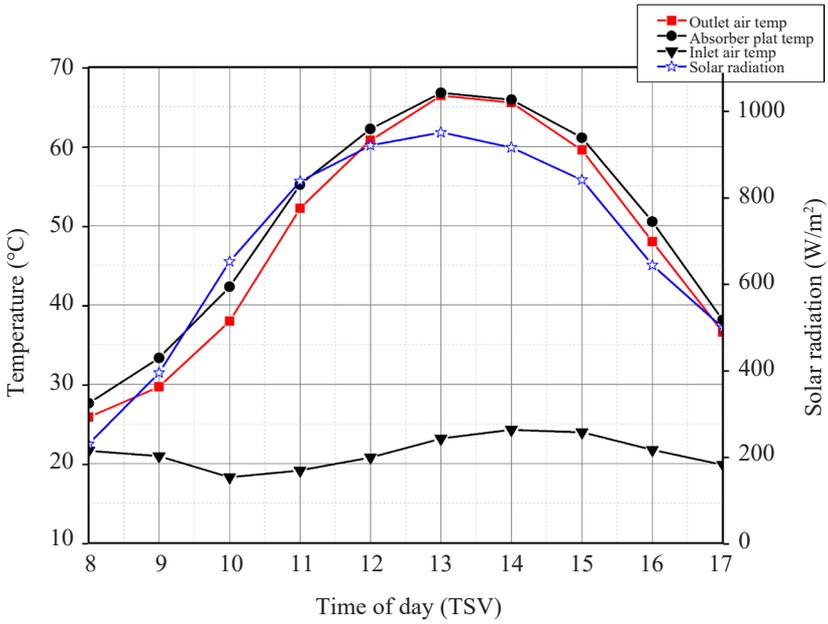


Figure 5: Temperature evolution versus the time of the day on 21 June 2015 for corrugated solar air collector under natural convection.

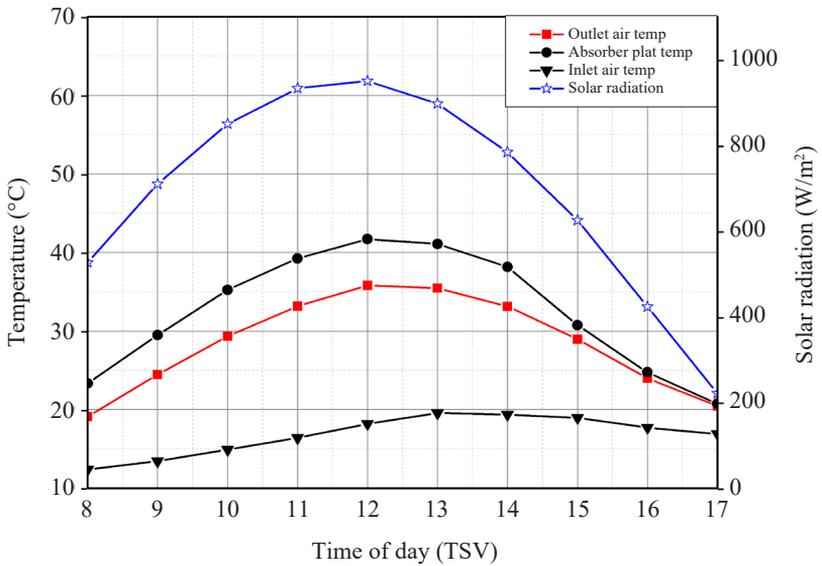


Figure 6: Temperature evolution versus the time of the day on 24 June 2016 for corrugated solar air collector under forced convection.

4. THE EFFICIENCY VARIATION OF THE SOLAR COLLECTORS SYSTEMS

The thermal efficiency of a collector is defined as the ratio of the useful energy to the incident solar energy.^{7,8} It is given by the following equation:

$$\eta = m C_p (T_{out} - T_{in}) / (I A_c) \quad (1)$$

where m (kg s^{-1}) is the air mass flow rate, C_p ($\text{J kg}^{-1} \text{K}^{-1}$) is the specific heat of the fluid, A_c (m^2) is the area of the collector, T_{in} ($^{\circ}\text{C}$) is the inlet temperature of the working fluid, T_{out} ($^{\circ}\text{C}$) is the outlet temperature of the working fluid and I (W m^{-2}) is the solar radiation.

The mass flow rate equation (m) is:

$$m = \rho Q \quad (2)$$

where ρ (kg m^{-3}) is the density of air and Q ($\text{m}^3 \text{s}^{-1}$) is the volume flow rate.

The efficiency calculation of the polyethylene absorber collector leads to relatively low values, not exceeding 30%, even with a fan with an air flow rate of $320 \text{ m}^3 \text{ h}^{-1}$.

Figure 7 presents the efficiency variation in the case of corrugated absorber made of aluminium sheet for sunny days. It is seen from the results in Figure 7 that the solar air collector with corrugated aluminium absorber has a high efficiency. A similar result has been found by Gao et al.¹⁰ They found that the efficiencies of the two types of cross-corrugated collectors are high, about 58.9% and 60.3%, respectively. The efficiency increases with the enhancement of heat transfer by turbulence. The study revealed that the collector under forced convection for an air flow rate of $150 \text{ (m}^3 \text{ h}^{-1}\text{)}$ reached a maximum efficiency of 77%, whereas with natural convection reach a maximum of 65%. Due to the increases of air mass flow and the cylinders width constituting the absorber cause a larger heat transfer to the flowing air, resulting a high efficiency of the collector. The results obtained in this study are very similar to a number of studies.^{3-9,11} In accordance with these references, a tight air channel which the width is between 7.5 cm and 10 cm results in a significant improvement in the performance of the collector. In addition, the collector efficiency improves with increasing of mass flow due to improved heat transfer to the air flow.

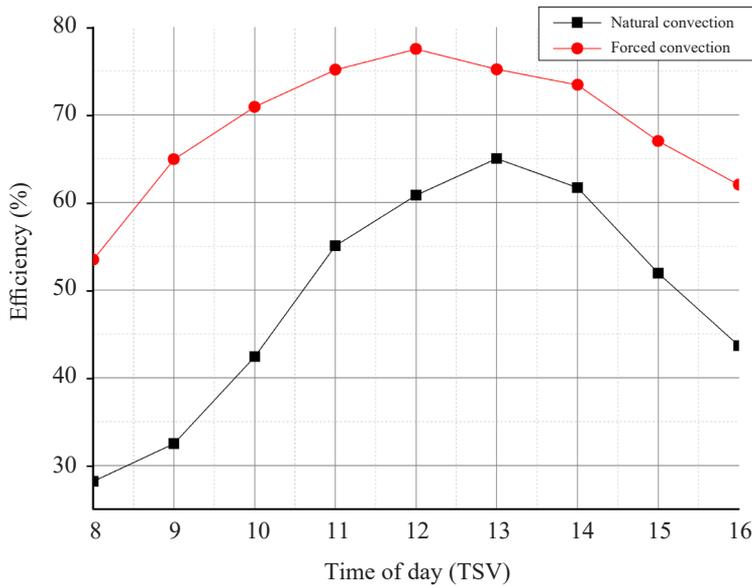


Figure 7: Variation of thermal efficiency of the corrugated solar air collector.

5. CONCLUSION

This article presents a new design of the absorber of the solar air collector. Thus, the experimental study was carried out on two types of solar air collectors designed for indirect solar dryer. The comparison between the two collectors shows that the corrugated aluminium absorber collector has better thermal performance than that of polyethylene. Thanks to the wavy shape of the two superimposed aluminium plates constituting the absorber, we obtained cylinders of diameter satisfying a good air circulation. The results show that the temperature of the air at the outlet of the collector is more important under natural ventilation. The efficiency of the collector with corrugated aluminium absorber improves with increasing air flow rate.

6. ACKNOWLEDGEMENTS

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