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Experimental Study of Solar Air Dryer Performance Utilized with Flat and Perforated Absorber Plates

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Abstract

In order to determine if perforated absorber plates with circular holes of 6 mm and 3 mm diameter, respectively, in the solar collector enhance the performance of a dryer compared to the traditional flat absorber plate, an experimental investigation was conducted under Iraqi climatic conditions to investigate the enhancement of the performance of an indirect solar air dryer system with forced convection. The experiments were conducted in June 2024 at Baghdad city, located at 33.3°N latitude. A solar air dryer comprises a solar air collector inclined at 30° towards the south, an electric fan, and a drying chamber. In the present study, the surface of an absorber plate was modified by forming circular holes on the surface of the plate, which contributes to breaking the thermal barrier layer on the plate and thus improving the heat transmission from the hot plate to the air. Modifying the absorption plate results in a heightened thermal efficiency of the solar air collector compared to the traditional flat absorber plate. The results confirmed that the solar collector with a perforated absorption plate enhanced the solar dryer's effectiveness. A perforated plate with a diameter of 3 mm outperformed both the perforated plate with a diameter of 6 mm and the flat absorber plate. Results indicated that using the perforated plate with a diameter of 3 mm resulted in a 50.32% improvement in collector thermal efficiency and a 27% improvement in dryer efficiency when compared with the perforated plate with a diameter of 6 mm and the flat absorber plate.

Keywords: indirect solar air dryer, perforated absorber plate, forced convection, collector thermal efficiency, dryer efficiency, drying chamber.

1. Introduction

The Process of drying food goods reduces the water content within the product to levels that limit bacteria development and so allow for their preservation in clement conditions [1]. However, using fossil fuels for drying is expensive and harmful to the environment, so adopting renewable energy sources, especially solar energy, will provide a practical and suitable solution. Solar dryers that use solar heat are considered technologies that maintain the protection of products with high efficiency and performance [2]. Indirect solar drying is an important technique for preserving vegetables and fruits. Maintaining food production during the harvest and sale seasons is necessary to balance population and food demand. Indirect drying provides greater possibilities in the drying process, as it was not directly exposed to sunlight, thus protecting it from ultraviolet rays that may harm the product. Drying occurs indirectly through convective heat transfer from hot air to products to be dried [3] [4]. Farhan and Sahi [5] designed and manufactured three solar air collectors with and without perforation absorber panels. The best exit air properties were obtained using a perforated absorber plate. Dutta et al. [6] conducted a numerical study to assess double-pass solar air heaters employing two types of absorber plates: a perforated plate and a flat plate. The simulations were performed using ANSYS FLUENT 18.1, using the finite volume method and the standard k-ε model for turbulence.

The results showed that the solar heater with a perforated plate resulted in a notable increase in air temperature compared to the flat plate at an air mass flow rate of 0.08 kg/s. Khidhir [7] developed and manufactured an indirect solar dryer with forced convection to evaluate drying performance in the specific weather conditions of Erbil/ Iraq. The experiments were conducted over two days (October 29-30), during which eggplants were dried. Results showed that the best drying time was between 9:00 and 16:00, with air temperature reaching around 40°C when solar radiation exceeded 600 W/m². Jadallah et al. [8] designed a solar air dryer forced convection with a photovoltaic-thermal dual counterflow system for crop drying. The system's efficacy and robustness were tested by drying banana slices, which demonstrated the ability to dry in substantial percentages. Ramirez et al. [9] suggested

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the design of an indirect solar air dryer employing phase change material in the thermal structure of the dryer for thermal energy storage. The study aims to extend the system's operating time and improve its thermal performance at night. Fernandes et al [10] constructed and tested two indirect solar dryer prototypes to examine the drying of fruits and vegetables. Results showed the possibility of drying products at a low cost, with a loss of less than 10% of their original weight. Nhut et al. [11] conducted a set of experiments with crimped baffles to obtain a suitable temperature of air from the solar air collector outlet for an agricultural dryer in Bienhoa City, Vietnam. Kumar et al. [12] developed a computational model derived from experimental data to test the appropriate design for an indirect solar air dryer under both full-load and no-load operating conditions. It was concluded that incorporating forced convection using a fan could enhance the solar dryer efficiency. Ennissioui et al. [13] designed a natural convection indirect solar dryer for Meknes, Morocco's geographical and climatic conditions. They performed an experimental study to assess its effectiveness. In order to assess the impact of the indirect solar dryer technique on banana dehydration, a comparison was conducted with sun drying. The findings indicated that the indirect solar dryer resulted in a more marked drop in moisture compared to sun drying. Gilago and Chandramohan [14] investigated experimentally the evaluation of indirect solar dryers operating under both forced and natural convection modes for drying ivy gourd. The results showed that the collector's thermal efficiency with forced convection was higher than that with natural convection. Jassim and Shbailat [15] evaluated five varieties of solar air collectors: a traditional channel with smooth absorbing plate (pattern I), a double channel with smooth absorbing plate (pattern II), a double channel with perforating "V" corrugated absorbing plate (pattern III), a double channel with an internal wire mesh connection (pattern IV), and a double channel using transparent honeycomb as a heat absorbing sheet (pattern V). Compared with other cases, the best results were employing the pattern (III). Chouikhi and Amer [16] studied experimental and numerical to assess the performance of an indirect forced convection solar dryer using a photovoltaic/thermal (PV/T) air collector for drying tomato slices. Experiments were carried out over two days, with continuous monitoring of temperature, humidity, and sample mass. The simulation results closely matched the experimental data. The average efficiencies recorded were 30.9% for the solar collector, 15.2% for the dryer, and 8.7% for the PV panel. Al-Juamily et al. [17] experimentally tested solar drying collectors to determine their capacity to heat air and extract moisture from products. The findings indicate that the air temperature that entered the dryer was the most influential factor for the drying rate. Kokate et al. [18] created an indirect solar dryer for drying onion and garlic products and evaluated its performance by comparing it with traditional solar drying. They determined that an indirect dryer was more effective than traditional solar drying. Tagne et al. [19] performed a study that evaluated the effectiveness of an indirect solar dryer designed specifically for the purpose of drying cocoa beans. The drying process involved natural convection throughout the night and forced convection throughout the day. Bhavsar and Patel [20] studied the effectiveness of solar air dryer with forced and natural convection mechanisms for ginger product drying. The objective was to investigate the loss of moisture content and ginger weight during drying. A forced convection drying method resulted in a more significant weight reduction than the natural convection over the same drying period. Demissie et al. [21] fabricated an indirect solar food dryer in Mekelle, Ethiopia. A three-dimensional computational fluid dynamics (CFD) model and simulation were performed to forecast the temperature distribution and flow velocity patterns inside the dryer. Srivastava et al. [22] conducted an experimental study to assess the performance of an indirect solar dryer in drying potato slices, and compared it with traditional open-sun drying. The findings showed that the moisture content dropped in potato slices from 83% to 7.7% after 16 hours using the dryer, compared to 11.7% when using open sun drying. Vijayan et al. [23] developed a indirect solar air dryer with forced convection and porous layer-sensitive heat storage under Coimbatore's climatic conditions for drying gourd slices. Srithanyakorn et al. [24] studied the improvement of the efficiency of a mixed solar dryer forced convection by enhancing the transferring heat of the solar collector using stainless steel wire mesh placed on the absorber plate within the collector. Mahmood [25] executed an experimental investigation to assess the thermal performance of a double-pass solar air collector with phase change material (PCM) for thermal storage under the climatic conditions of Baghdad, Iraq. The results showed that when using the PCM increased the outlet air temperature by 1.5-6.5 °C above the ambient temperature after sunset for a period of 5 hours. Arunkumar et al. [26] developed and designed an indirect solar dryer for drying red chili. Paraffin wax and glass fragments were incorporated as natural materials to retain thermal energy in the solar collector. Results found that the developed indirect solar dryer with combined paraffin wax and glass fragments resulted in sustained drying time and enhanced product quality. Yassen et al. [27] designed and experimentally tested two new solar dryers: a new mixed indirect solar dryer and a new indirect solar dryer. This study compared the suggested solar dryers with a standard indirect solar dryer to understand their thermal performance further. The results found that the thermal efficiencies of the new mixed indirect solar dryer and the new indirect solar dryer were 55% and 9%, respectively, higher than the standard indirect solar dryer. Natarajan et al. [28] executed an experimental investigation to evaluate the efficacy of forced and natural convective drying techniques in comparison with the conventional open-sun drying method. Tested how well each technique reduced the grapes' moisture content. The results demonstrated that forced convection reduced the moisture content of grapes by an astounding 83.21%, whereas open-sun drying reduced it by 30.5% over three days. On the other hand, natural convection removed 82.35% of the moisture, while open-sun drying removed 25.05%. Babar et al. [29] developed and manufactured a passive solar dryer with a smooth absorber panel collector for drying agricultural products. Mushrooms were dried in the passive dryer and compared to sunlight drying. The samples' moisture ratio was zero after 21 hours of drying in a passive solar dryer and 33 hours in the sunlight drying. The solar dryer passive took 36.36% less time than sunlight drying. The solar dryer passive can dry samples in 35–40% less time than the sunlight drying.

From the review mentioned above, there has been a growing emphasis on enhancing the performance of indirect solar dryers for drying various agricultural products. However, most of the previous works have mainly focused on flat absorber plates or general design modifications, while limited attention has been given to the effect of using perforated absorber plates and their impact on heat transfer to the air. Moreover, there is a lack of comprehensive experimental validation under hot and dry climate conditions, such as those found in Baghdad. This gap highlights the need for further investigation to assess the effectiveness and performance of these systems, which is the focus of the current study. The main objective of this study is to compare the performance of a flat absorber plate with that of a perforated absorber plate in an indirect solar air dryer system under the climatic conditions of Iraq. A low-cost indirect solar air dryer was designed and fabricated using locally sourced, eco-friendly materials. The study involves measurements and analyses of essential parameters, including solar radiation, collector thermal efficiency, dryer efficiency, temperatures at various points in the system, drying rate, weight of dried sample, moisture content, and air relative humidity. Therefore, this investigation is proposed to address this weakness and analyze the effectiveness of the solar air dryer system.

2. Experimental Apparatus and Procedure

Indirect solar air dryer forced convection was developed and constructed to dry food, particularly vegetables and fruits. It was fabricated using inexpensive and eco-friendly materials. The experimental apparatus comprised two main components: solar air collector and drying chamber. Figure 1 and Figure 2 show the experimental apparatus schematically and photographically.

2.1. Solar Air Collector

Figure 3 (a) and (b) show the dryer's primary component, the solar air collector. It consists of an absorption plate that heats the air and a glass cover that generates the greenhouse effect, so that as much of the heat generated by solar radiation as possible can be contained by air entrapped between the glass cover and absorber plate. It transfers this power to the product inside the dryer [13]. The solar air collector's primary frame was constructed from wood (18 mm thickness) to prevent heat loss. The dimensions of the solar air collector are (100 × 80 × 20) cm in length, width, and height, respectively. The solar collector was sloped with an angle of 30°[30]. Three absorber plate samples were constructed. The first plate was traditionally flat; the second and third plates were perforated with circular holes of 6 mm and 3 mm diameter, respectively, as represented in Figure 4. The absorber plate dimension (80 × 80) cm and has a thickness of 1 mm. It was manufactured from aluminum and coated in matte black to enhance heat absorption. A transmittance acrylic sheet (t = 4 mm) was used to cover the collector roof structure, which had a dimension of (100 × 80) cm. The distance between the absorber plate and the acrylic sheet was 17 cm for air circulation. The solar collector is thermally insulated from all sides using a 20 mm thick glass wool layer to reduce heat losses. A 120 mm diameter axial fan is set up at the solar collector outlet to draw outside air through the intake of the solar collector to the drying chamber. The air duct is constructed from aluminum and insulated with glass wool. It has a diameter of 120 mm and a length of 50cm, facilitating the transfer of heated air from a solar collector to the dryer without any heat losses.

2.2. Drying Chamber

The drying chamber structure is constructed from wood with a thickness of 18 mm and has dimensions of (75 × 75× 105) cm in length, width, and height, respectively. The drying chamber was thoroughly insulated on all sides with 20 mm thick glass wool to reduce heat loss. It contains three trays made of aluminum mesh, each measuring (65 × 75) cm, with a space of 20 cm between each tray. The vertical air distribution channel built into the drying chamber is designed to distribute hot air that enters the chamber evenly on each tray. The solar dryers' performance and dried product quality were enhanced by an integrated air distribution system [31], as shown in Figure 5 (a). The dimensions of the wood-made dryer door were (75 × 100) cm. The hot air rises between the trays and exits through a circular opening measuring 180 mm in diameter, situated at the upper part of the back of the dryer, to facilitate and control airflow through the dryer, as shown in Figure 5 (b).

2.3. Experimental Procedure

Experiments were carried out using various absorber plates to assess the effectiveness of a forced convection indirect solar air dryer in Baghdad's weather conditions. The experiments were conducted in June 2024. All experimental tests commenced at 08:00 AM and concluded at 16:00 PM. The data was recorded hourly. Important parameters in the experiment included the following: solar radiation, surface temperature of the absorption plates, air relative humidity, temperature of the air at the intake and outflow of the collector, dried sample weight, and temperature of the air on trays. The airflow rate entering the chamber was maintained steady at 0.0113 m^3/s throughout all experimental tests. A fan regulator was installed at the exit of the solar air collector to stabilize the fan speed. The recorded values were used to assess the effectiveness of the indirect solar air dryer system. Accurate temperature readings are obtained using type-k thermocouples that have an uncertainty of ± 0.1°C. These thermocouples are connected to the temperature data logger (AT4532x) and include a 32-channel. To determine the mass of the dry food samples, a digital weighing scale was utilized, which has a capacity of 10,000 g and an accuracy of ±0.1 g. A digital data-logging hot wire anemometer (YK-2005AH) was used to measure the airflow velocity at the dryer's entrance. Environment Meter (EM-9000), with a range between 0 to 95% R.H., was used to measure the air's relative humidity, with an accuracy of ± 3% and a resolution of 0.1%. Hourly solar radiation data was taken from the Ministry of Science and Technology / Renewable Energy Department for Baghdad city, where the latitude coordinate is 33.3°N. About 3 kg of apricots were used to examine the system's efficiency in drying agricultural products. The quantity of apricots was about 80% relative humidity. The product was washed off with clean water, and the cores were removed. The product was left to dry before being uniformly distributed on three trays, and its weight was scaled before drying. The loss of humidity was estimated by determining the weight loss; the product is weighed every hour using the digital weighing scale.

2.4. Measurement Devices and Experimental Uncertainty

To ensure the accuracy of the experimental results, it is essential to acknowledge the uncertainty associated with the measurement devices used in the study. All devices were used according to the manufacturer’s instructions to minimize error and ensure reliable measurements. Table 1 presents the main devices and their respective uncertainties.

Table 1. Measuring Devices and Uncertainty of the Devices Used:

Device	Type	Measured Parameter	Uncertainty
Thermocouple	Type K	Air Temperature	± 0.1°C
Data Logger	AT4532x	Temperature (multi-channel)	± 1.2°C
Digital Weighing	SF-400	Sample Weight	±0.1 g
Hot Wire Anemometer	YK-2005AH	Air Velocity	± 5%
Environment Meter	EM-9000	Relative Humidity	± 3%

3. Thermal Analysis

Experimental calculation evaluated the effectiveness of the solar dryer, which was utilized with a flat and perforated absorber plate. Air mass flow rate ($\dot{m}$) moves towards the dryer calculated by multiplying air density (ρ), the area of the airflow duct (A_{duct}), and airspeed (v) as shown in Equation 1 [32].

$$\dot{m} = \rho \, v \, A_{duct} \quad (1)$$

Where $\dot{m}$ is the mass flow rate (kg/s), ρ is the air density(kg/m^3), v is the air speed (m/s), A_{duct} is the area of the airflow duct (m^2)calculated as:

$$A_{duct} = \frac{\pi}{4} d_{duct}^{2} \quad (2)$$

The collector's useful heat energy (Q_u) was obtained using Equation 3 [32].

$$Q_u = \dot{m} \, C_p (T_{out} - T_{in}) \quad (3)$$

Where C_p is specific heat (J/kg.°C), T_{in} is the temperature of the solar collector inlet (°C), and T_{out} is the temperature of the solar collector outlet (°C).

The input thermal solar radiation (Q_{solar}) into the solar collector can be calculated using Equation 4 [32].

$$Q_{solar} = I \, A_c \quad (4)$$

Where I is the total value of the solar radiation intensity (W/m^2), and A_c is the area of a collector(m^2).

The solar air collector's thermal efficiency (η_c) can be calculated using Equation 5 [32].

$$\eta_c = \frac{Q_u}{Q_{solar}} \quad (5)$$

The moisture content of the food decreased during the drying process, and the following Equation 6 can be used to calculate the percentage of moisture content (MC) [33].

$$MC(\%) = \frac{m_i - m_f}{m_i} * 100\% \quad (6)$$

The mass of the sample before and after drying is represented by m_i(kg)and m_f(kg), respectively.

The evaporated water mass (m_w) can be calculated using Equation 7 [34].

$$m_w = \frac{m_i \, (M_I - M_F)}{100 - M_F} \quad (7)$$

The initial and final moisture content is represented by M_I(%)and M_F(%), respectively.

The drying rate (m_{dr}) can be calculated using Equation 8 [34].

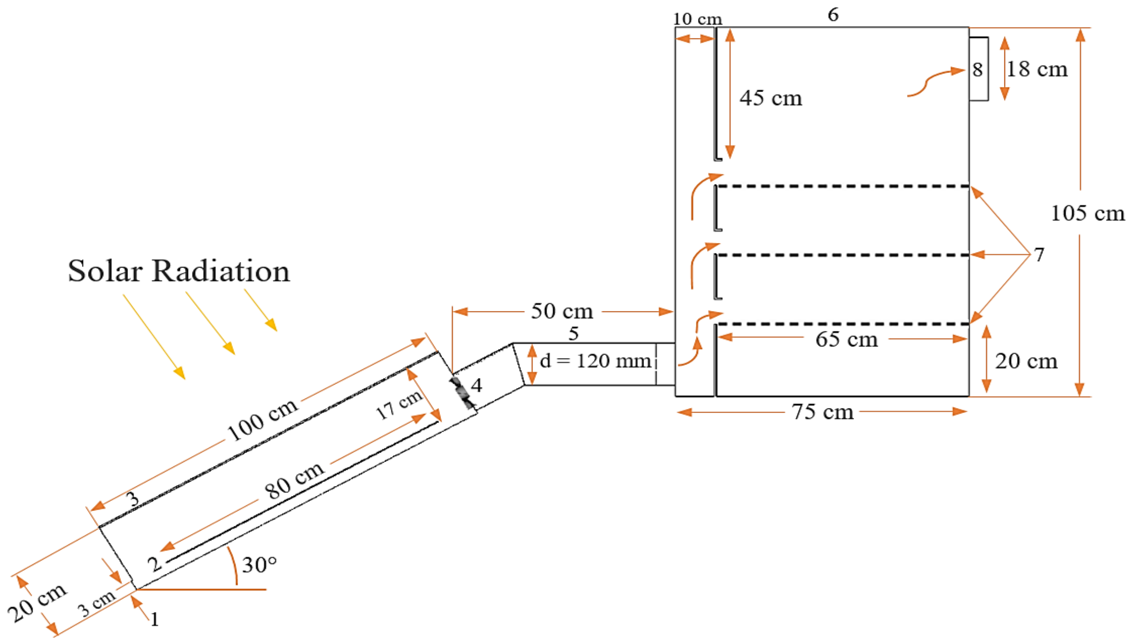
$$m_{dr} = \frac{m_w}{t_d} \quad (8)$$

Where t_d is the overall drying time (hr).

Dryer efficiency(η_d) for a solar dryer can be calculated by the following Equation 9 [7].

$$\eta_d = \frac{m_w \, h_{fg}}{I \, A_c \, t_d} \quad (9)$$

Where h_{fg} is the latent heat vaporization for water from steam tables = 2270 kJ/kg at a mean temperature.



1. Air inlet 2. Absorber plate 3. Acrylic sheet 4. Fan
5. Duct 6. Drying chamber 7. Trays 8. Air outlet

Figure 1. Schematic diagram of the experimental apparatus.

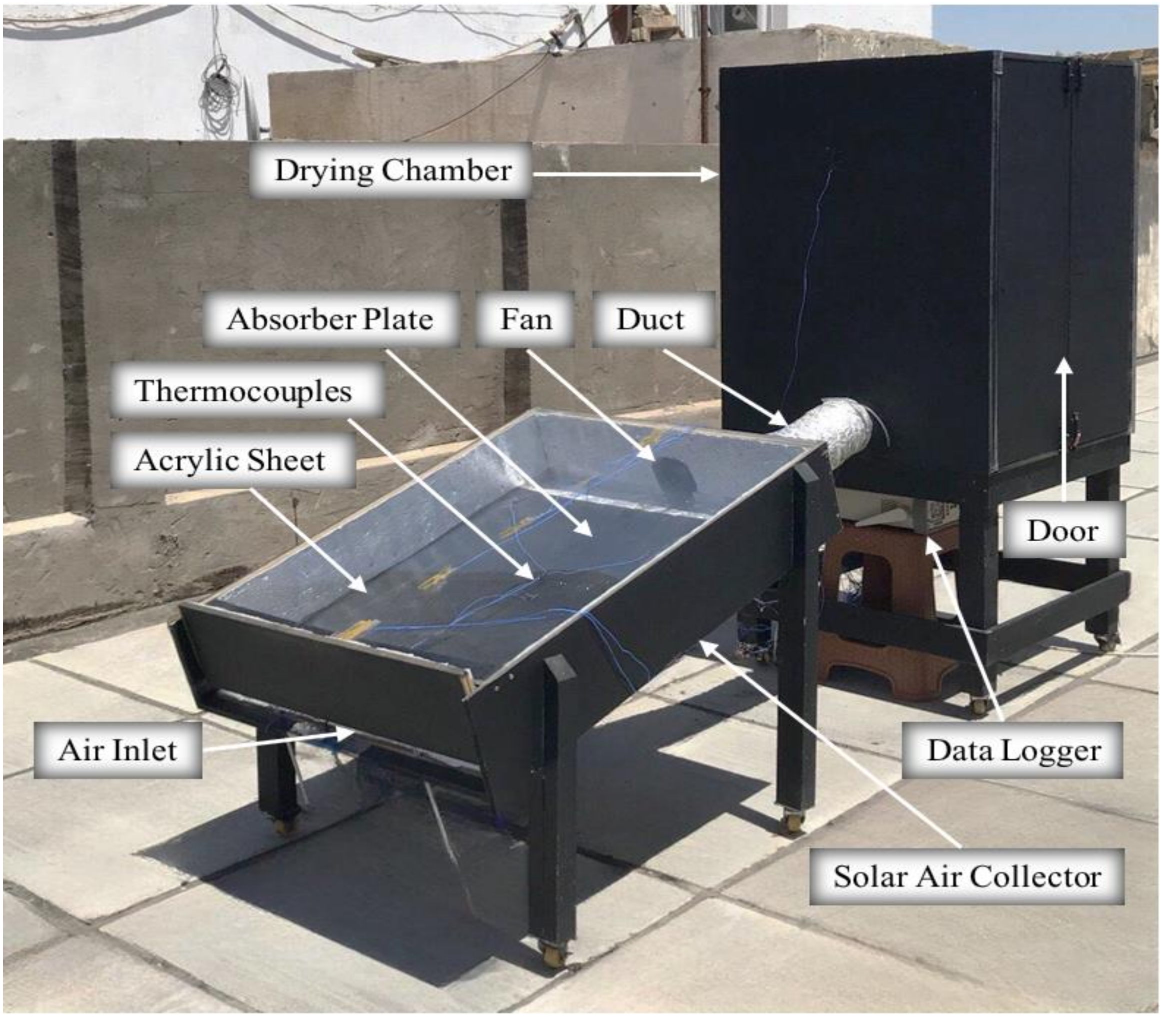
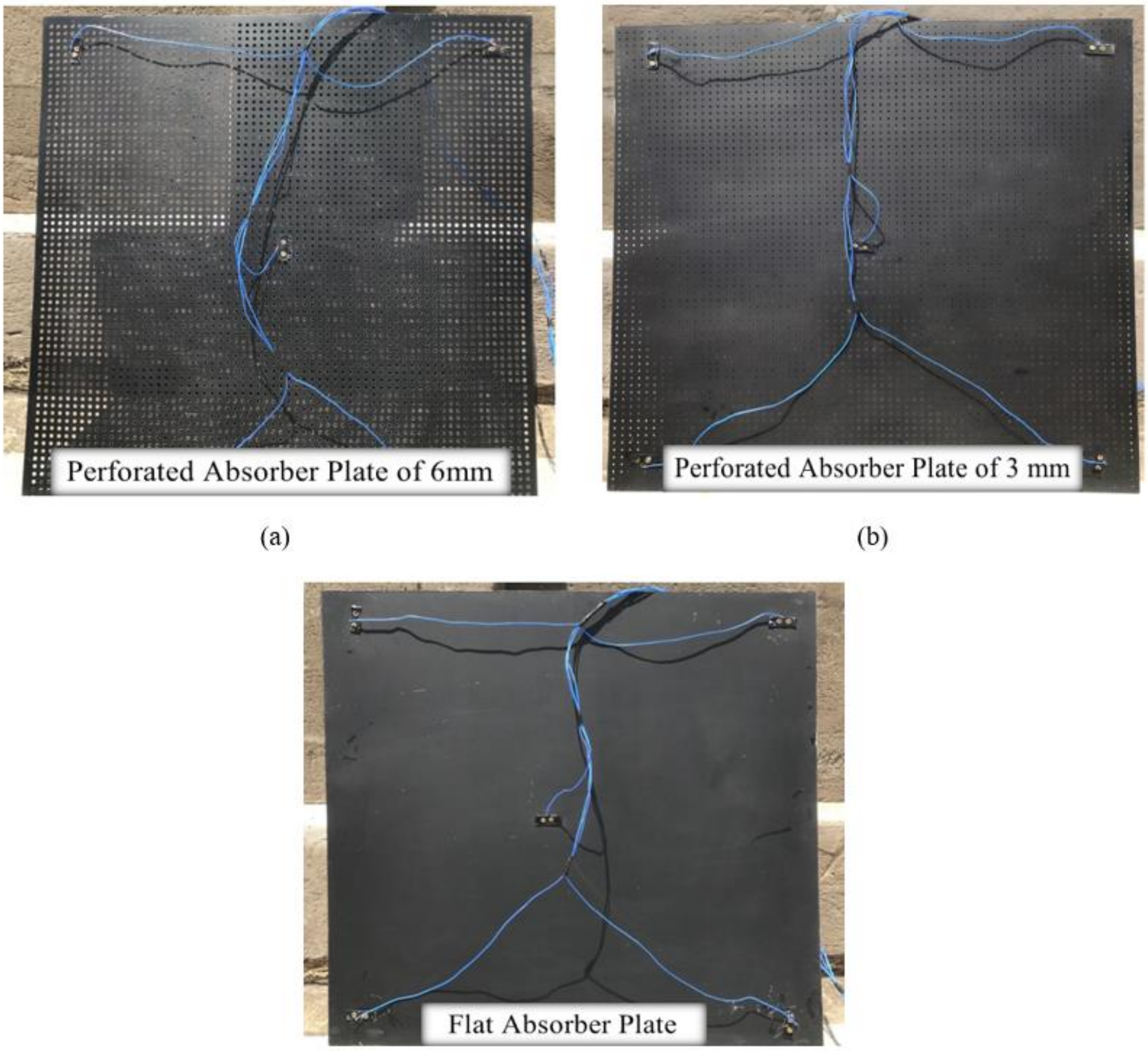


Figure 2. Photograph of the experimental setup of the indirect solar air dryer

(a) (b)

Figure 3. Photographs of the solar air collector: (a) Top view, (b) Side view.



(a) (b)

(c)

Figure 4. Types of absorber plates used in the solar air collector: (a) Perforated absorber plate with a diameter of 6 mm, (b) Perforated absorber plate with a diameter of 3 mm, (c) Flat absorber plate.

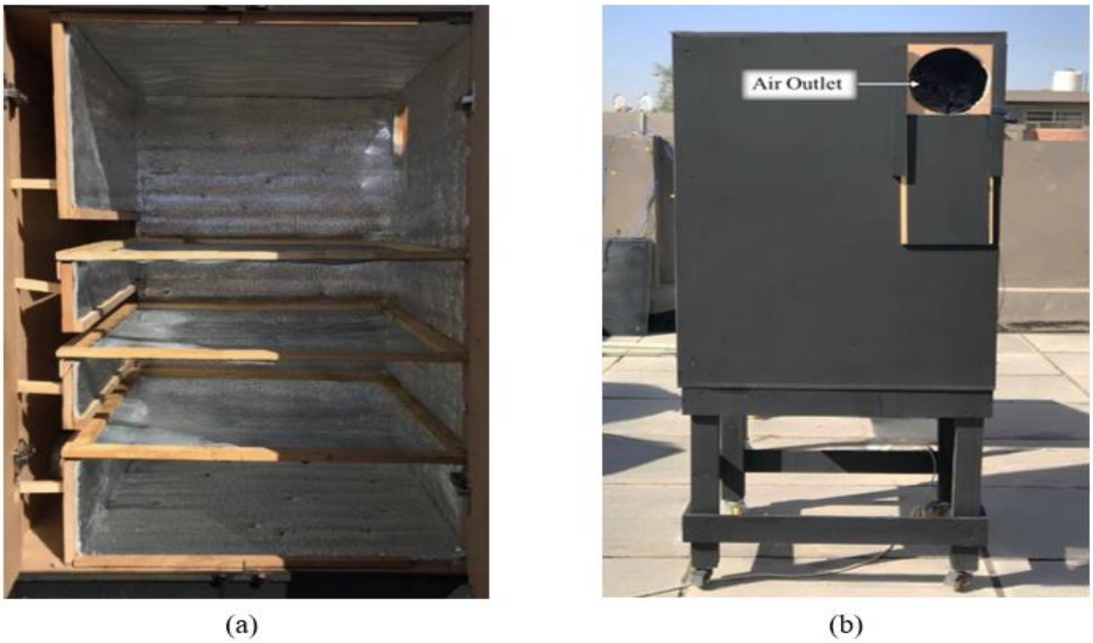


Figure 5. Photographs of the drying chamber: (a) Internal view showing tray arrangement, (b) Rear air outlet of the drying chamber.

4. Results and Discussion

The experimental results were presented and analyzed to investigate the impact of altering the absorber plate on the solar air dryer's performance using the perforated plate and compared to the traditional flat plate.

Figure 6 presents the variation of solar radiation intensity from 09:00 AM to 16:00 PM in June 2024. The solar radiation rises in the early morning, peaks around 1:00 PM, then decreases and disappears at sunset. The maximum solar radiation recorded is 822 W/m^{2}at 13:00 PM. The figure shows the variation in intensity of solar radiation over three consecutive days, June 7, 8, and 9, during which the readings were obtained, varies according to the weather conditions. The three curves show a slight difference in solar radiation intensity of ± 1 to 25 W/m^2.The variation in solar radiation has a direct impact on the performance of the solar collector, as higher radiation increases the amount of energy absorbed by the absorber plate, thus enhancing from the heating of the air entering the dryer.

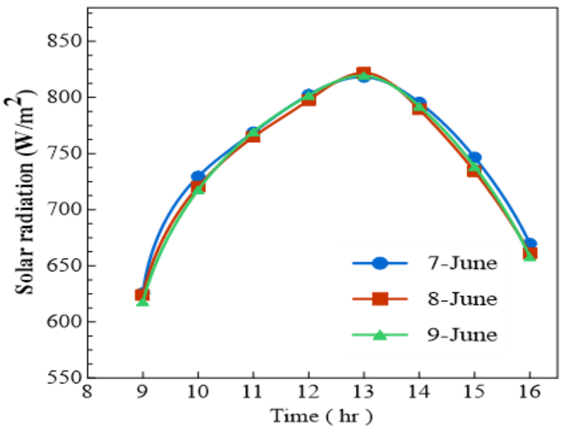


Figure 6. Hourly variation of solar radiation intensity during the experiment.

The variation in average surface temperature of the absorber plate for the perforated plate and flat plate with time is shown in Figure 7. The figure shows that the average surface temperature of the flat absorber plate is higher than that of the perforated absorber plates with circular holes of 6 mm and 3 mm diameter, respectively, because the flat plate has a smaller surface area than the perforated plate. It can be noted that the presence of holes in the plate increases the surface area of the plate, which enhances convective heat transfer and contributes to increased airflow within the solar collector. It can also be observed that the average surface temperature of the 6 mm diameter perforated absorber plate is higher than that of the 3 mm diameter perforated absorber plate due to the different number and diameters of holes, which cause the surface area of the absorption plate to differ.

The rise in air temperature is the result of the thermal energy gained by the air as it flows through the solar collector, which is the difference between the temperature of the air at the intake and its temperature at the exit of the collector. From Figure 8, it is noted that the difference of the air temperature (ΔT) increases with a perforated absorber plate with a diameter of 3 mm compared to a 6 mm diameter perforated absorber plate and the traditional flat absorber plate. This is because the perforated plate with a diameter of 3 mm enhances convective heat transfer by allowing air to pass through the perforations, increasing the heat exchange area and improving heat transfer from the plate to the air. As a result, the perforated plate with a diameter of 3 mm was more efficient in increasing the air temperature difference. It can be noted that the air temperature difference (ΔT) reached its maximum between 11:00 AM and 12:00 PM, as the buoyancy force increased as the solar radiation intensity increased. Thus, the induced airflow increases due to the increase in air temperature differential.

The effect of perforated and flat absorber plates on the performance of the thermal efficiency of the solar collector is shown in Figure 9. The solar collector's thermal efficiency depends on the air temperature differential (ΔT) and the solar radiation intensity. The maximum value of a collector's thermal efficiency using the traditional flat absorber plate and perforated absorber plates with circular holes of 6 mmand 3 mm diameter are 43%, 47.2%, and 50.32%, respectively, at noon.The results show that using a perforated plate with a diameter of 3 mm resulted in the highest thermal efficiency. This improvement in thermal efficiency is due to the increased heat exchange area resulting from the perforations, which enhances heat transfer from the plate surface to the air.

Dryer efficiency is an indicator used to assess the effectiveness of the drying system [7]. Figure 10 illustrates the dryer's efficiency with the time. From the figure, it can be noted that the presence of the 3 mm perforated absorber plate in the collector improves the dryer efficiency compared with the 6 mm perforated absorber plate and the conventional flat absorber plate. This improvement is attributed to the increased heat transfer from the plate surface to the air, which resulted in a higher air temperature entering the drying chamber, thus improving the evaporation process inside the chamber. The maximum dryer efficiency is recorded at approximately 27% for the perforated plate with a diameter of 3 mm, compared to 25% for the perforated plate with a diameter of 6 mm and 21% for the flat plate.

The drying rate signifies the velocity of dehydration occurring inside the drying chamber. The product's drying rate with the time for each hour during the drying process is shown in Figure 11. A decrease in the curve trend is observed during the initial drying stages, indicating a substantial evaporation process in the product due to the increased air temperature. In the period of falling rate, the drying process occurs when the surface of the product becomes unsaturated with water. Controlled the drying rate through the amount of moisture that evaporates from the inside of a product to its surface during the falling rate phase [35]. Over time, the drying rate decreases. The figure shows that using the 3 mm perforated plate resulted in the highest drying rate compared to the 6 mm perforated plate and the flat plate. This is attributed to the improved heat transfer efficiency from the plate to the air, which allowed the air to be heated more efficiently. Thus, increased the air's ability to carry moisture from the product surface, accelerating the drying process.

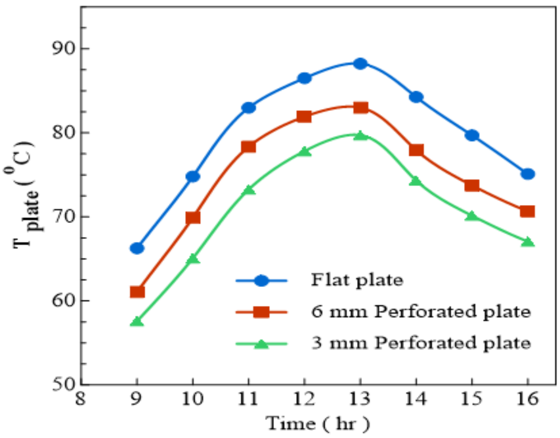


Figure 7. Average surface temperature for flat and perforated absorber plate with the time.

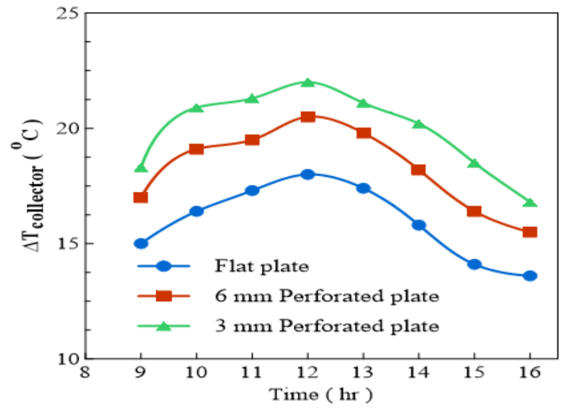


Figure 8. Collector air temperature difference by using flat and perforated absorber plate with the time.

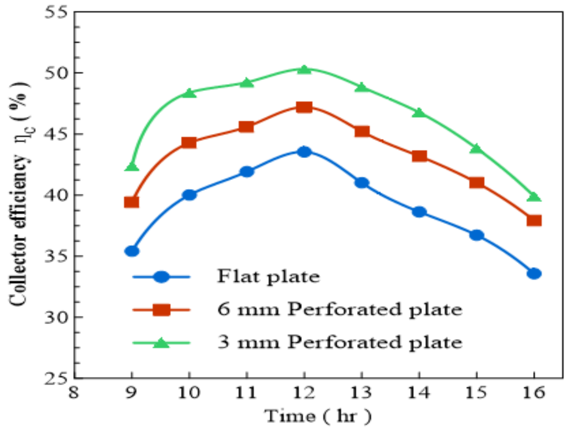


Figure 9. Variation of collector thermal efficiency by using flat and perforated absorber plate with the time.

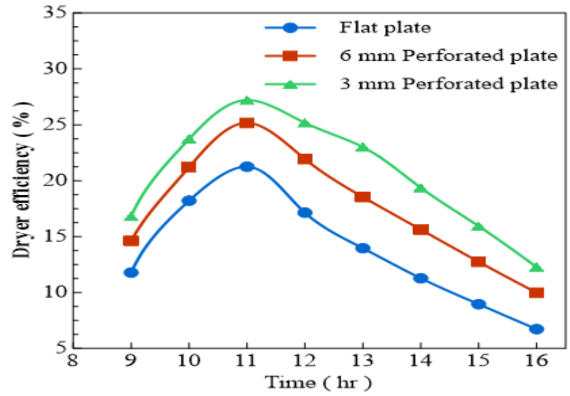


Figure 10. Variation of dryer efficiency with the time.

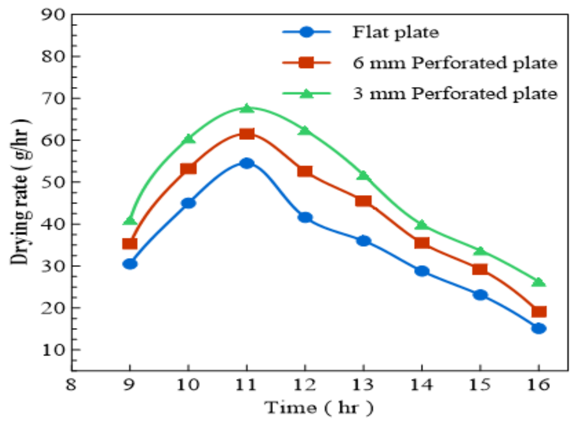


Figure 11. Variation of drying rate of apricots with the time.

The average temperature of the air on trays is shown in Figures 12, 13, and 14. There are no significant temperature differences in the trays (1, 2, and 3). The vertical air distribution channel integrated into the drying chamber improves the drying process by augmenting the uniformity of the hot air dispersion across trays. A uniform temperature distribution of drying air across the drying trays was noted. Figure 14 shows that the solar air collector using a perforated plate with circular holes of 3 mm diameter is optimal for a more efficient drying process.

Figure 15 illustrates the mass loss of the apricots with time. The initial weight of apricots before drying was 3 kg. After 8 hours of the drying process, the final weights of the apricots are 1.799, 1.747, and 1.701 kg, respectively, when using a traditional flat absorber plate and perforated absorber plates with circular holes of 6 mm and 3 mm diameter. The evaporation of moisture causes the product's mass to decrease. Thus, the product's water content decreases due to the airflow and air temperature conditions within the dryer during the drying process. From the figure, it can be noted that the highest apricot weight loss occurs using the 3 mm perforated plate. This means that using the solar dryer equipped with a perforated plate is optimal for practical applications in hot and dry environments, as it provides faster and more efficient drying, which reduces energy consumption, reduces drying time, and maintains the quality of the dried product.

Figure 16 illustrates the product's moisture content variation with drying time. After operating the system for about 8 h, the moisture content reduces from 80% to 47%, 45%, and 42%, respectively, when using a traditional flat absorber plate and perforated absorber plates with circular holes of 6 mm and 3 mm diameter. The figure shows that the solar dryer equipped with a perforated plate with circular holes of 3 mm diameter is most effective in removing moisture.

The variation in the air's relative humidity is shown in Figure 17. In general, at the beginning of the drying process, the air relative humidity is high due to the intense evaporation of surface moisture from the product. As the moisture content of the product declines, the evaporation rate gradually decreases, resulting in a lower relative humidity in the air exiting the dryer.

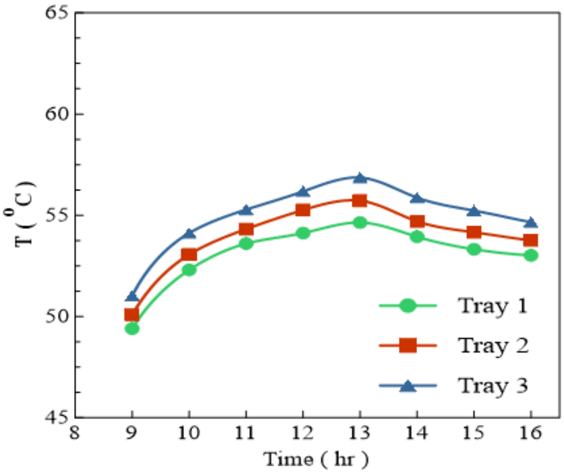


Figure 12. Variation of the average air temperature of each tray by using flat plate with the time.

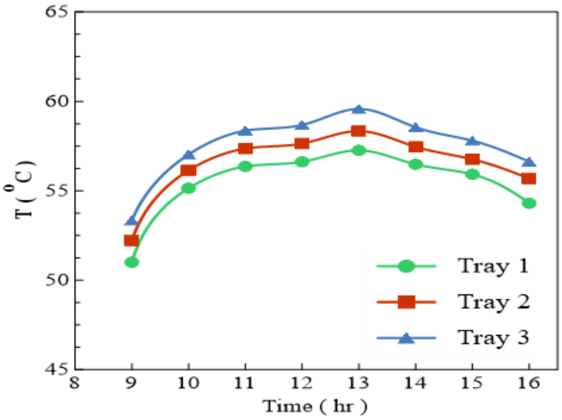


Figure 13. Variation of the average air temperature of each tray by using perforated plate with circular holes (6 mm) with the time.

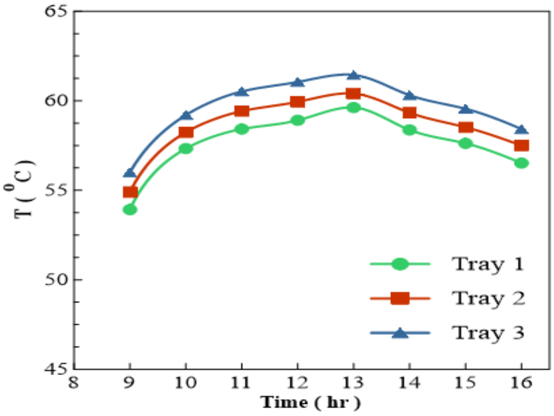


Figure 14. Variation of the average air temperature of each tray by using perforated plate with circular holes (3 mm) with the time.

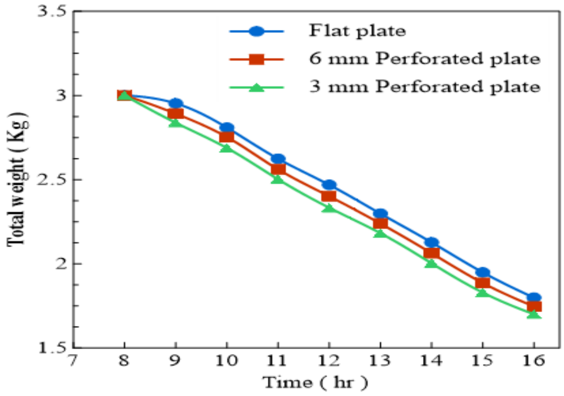


Figure 15. Variation of total weight of product with the time.

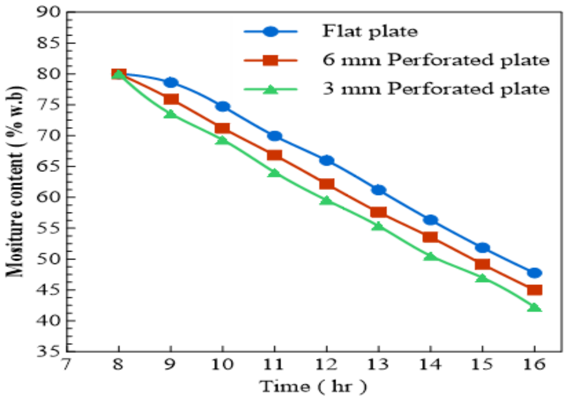


Figure 16. Variation of moisture content of apricots with the time.

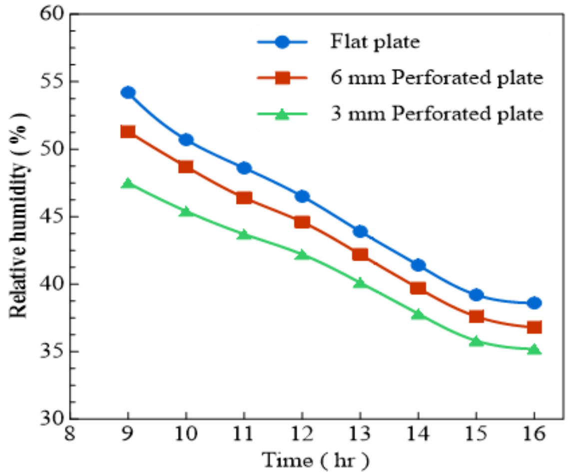
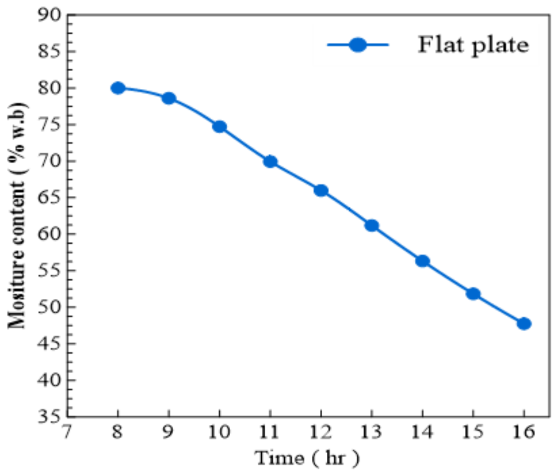


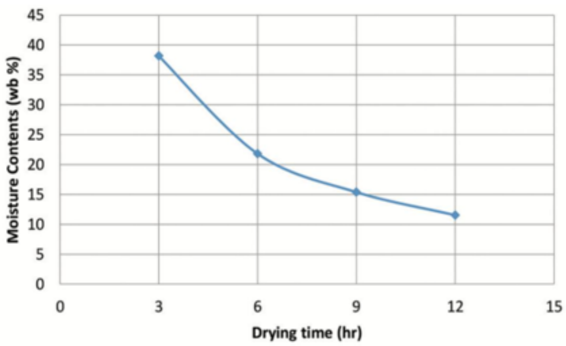
Figure 17. Variation of air relative humidity with the time.

4.1. Comparison with the Previous Experimental Works

The comparison of the present experimental results with those of other researchers will rely on the overall behavior of certain parameters that evaluate the effectiveness of the solar air dryer. Khidhir [7] studied the performance of an indirect solar air dryer with a flat absorber plate under the climatic conditions of Erbil, Iraq. Figure 18 illustrates the variation in moisture content of the product over time. The overall behavior of the moisture content aligns with the experimental results obtained in this study.



(a): Present Work - Apricot



(b): Khidhir [7] - Eggplant

Figure 18. (a) and (b) Comparison of the moisture content of the product with the time.

5. Conclusions

The purpose of this experimental work is to compare perforated absorber plates (with 6 mm and 3 mm diameters) with a traditional flat absorber plate in the solar collector on the performance of an indirect solar air dryer. The experimental investigation was conducted under Iraqi climate conditions. The main findings are summarized as follows:

1. The absorber plate's mean surface temperature was reduced when using perforated plates. The maximum drop in plate surface temperature for perforated absorber plates with circular holes of 6 mm and 3 mm diameter was about 5.92% and 9.63%, respectively, compared to the traditional flat absorber plate.
2. Increase in air temperature difference (ΔT) of the collector. The maximum rise in the difference air temperature when using traditional flat absorber plate and perforated absorber plates with circular holes of 6 mm and 3 mm diameter was about 18, 20.5, and 22 °C, respectively.
3. The collector's thermal efficiency increased when using a perforated absorbent plate, achieving peak values at 12:00 PM. The maximum improvement in collector thermal efficiency was recorded with the traditional flat absorber plate and perforated absorber plates with circular holes of 6 mm and 3 mm diameter, respectively, at approximately 43%, 47.2%, and 50.32%.
4. The highest dryer efficiency and drying rate are noticed in the early drying process times when using a perforated plate with a diameter of 3 mm, which is optimal for a more efficient drying process.

In conclusion, the use of perforated absorber plates, especially with 3 mm holes, enhances the thermal and drying performance of the indirect solar air dryer, making it suitable for practical applications in hot and dry climates.

Based on the findings of this study, it is recommended to conduct seasonal performance tests of the system under various solar radiation conditions to assess its year-round efficiency. It is also recommended to integrate perforated absorber plates with phase change materials (PCMs) or add thermal storage layers to maintain stable temperatures when solar radiation is low. Additionally, solar tracking systems can be integrated to increase solar exposure and improve efficiency.

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