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Development of Indirect Solar Dryer for Drying Onions Under Egyptian Conditions

Sameh A. EL-M. Khalifa[1], M. M. A. El-Sharabasy[1], M. R. Darwesh[2]

1. **Agric. and Bio-Systems. Eng., Dept., Fac. of Agric., Damietta Univ., Egypt**
2. **Agric. Structures and Environmental Control, Tanta Univ., Egypt**

Email address: profdrmoheb2014@du.e du.eg Mobile No.01008418272
Email address: rmdarwish@yahoo.com Mobile No. 01224074841
Corresponding author*: **eng.samehkhalifa2011@yahoo.com** Mobile no. 01014823855

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ABSTRACT

Applications of solar energy in dehydration process due to higher prices and shortages of fossil fuels, and to reduce the fuel consumption used in the dehydration processes. In addition, solar energy sources as they are freely available. So, the aim of this study was to develop and evaluate an indirect solar dryer to optimize the efficiency of solar air dryers.

A solar dryer consists of a solar flat plate air collector with V corrugated-absorption plates, an insulated drying chamber, and a chimney for exhaust air. The total area of the collector's is 1.5 m^2. The size of the drying cabinet is (80 cm length, 80 cm width, and 80 cm height). The qualitative analysis for drying onions showed that the moisture content of onions was reduced from an initial value of 85% (w.b.) to the final moisture content 5.66% to 6.54% (w.b). The dryer's efficiency per day was 39.3% and 42.3% at dryer (A) and dryer (B), respectively. Therefore, the use of the developed dryer led to an increase in the dryer's efficiency by 7.63% for the air flow rate of 2.8 m^3/min. While it was 34.1% and 38.82% at dryer (A) and dryer (B), respectively, the use of the developed dryer led to an increase in the dryer's efficiency by 13.84% for the air flow rate of 1.8 m^3/min.

1. INTRODUCTION

Drying processes have always been a great importance for conserving agricultural products in agricultural countries like Egypt. According to the **FAO (2020)** onions are one of Egypt's most important crops in terms of local consumption and exports, as they are the third most important export crop after oranges and potatoes. Egypt is among the top ten onion-producing nations worldwide. Onion cultivated area in Egypt is 87948 ha; Egypt's productivity of onions is close to three million tons. The exports of Egyptian onions, at end of 2019 recorded 550,000 Mg, compared to 310,000 Mg in 2018 in the form of fresh onions, and 16,000 to 20,000 Mg of dried onions are exported, producing from 150,000 to 200,000 Mg. Approximately, at a rate of 12.5 to 15.5% of the total production, the remaining 87.5 to 84.5% suffices for local consumption.

In agricultural nations such as Egypt, drying processes have traditionally been crucial for maintaining agricultural products. The most popular method of food preservation that prolongs food shelf life is dehydration. Moisture is taken out of food material and flown out by hot air in this simultaneous heat and mass transfer process. In the most tropical and subtropical nations, the most widely used method of preserving agricultural products is still open-sun dehydration, a well-known food preservation technique. **Bal *et al*. (2009)** created and developed a solar dryer that stores extra solar energy throughout the day using paraffin wax as Phase change material (PCM). When no solar energy is available, they discharge the hot air they have used, which is heated to temperatures similar to those exhausted by a normal solar collector. This suggests that there may be a way to reduce the energy needed for dehydration processes. Furthermore, they emphasized the potential for dehydration of food and agricultural items at consistent, moderate temperatures between 40 and 75°C. **Fudholi *et al*. (2010)** examined a wide range of solar dryer designs that have been created to dry various agricultural and marine materials. The quantity of products that are dried is a crucial factor that impacts the efficiency of a solar dryer. A larger amount of drying air is needed for the highest solids load. This raises the possibility of receiving dried goods of low quality since the materials may not be able to reach the appropriate moisture content. On the other hand, adding a small amount of dried items speeds up the solar dryer's dehydration processes, although occasionally this could result in energy loss. **Esakkimuthu *et al*. (2013)** used PCM (HS 58, melting point 58 °C) in their solar dryer, which is indirect. Their storage system can maintain an air temperature over 50 °C for four hours while discharging at a mass flow rate of 0.0555 kg/s. They came to the conclusion that the drying system performs better when PCM is used. Provided an experimental analysis of a PCM-equipped indirect solar dryer. The dehydration chamber is a component of the solar dyer and a single-glazed flat plate solar collector that is combined with paraffin wax, a phase-change material. Modules of the PCM are prepared and evenly spaced out over the absorber plate. **Kumar *et al*. (2014)** presented a state-of-the-art review of several designs, details of constructional features, and operational principles of a wide variety of practically realized solar dehydration systems. **Morales *et al*. (2014)** said that today, one of the most complex challenges facing humanists is managing and controlling the climatic conditions produced by overexploitation of natural sources. **Reyes *et al*. (2014)** carried out an experimental study of mushroom dehydration on the hybrid solar dryer with PCMs. The dryer contains a solar panel, a solar energy accumulator (which contains paraffin wax as phase change material), a centrifugal fan, an electrical heater, and a dehydration chamber. The efficiency of the accumulator solar panel varied between 10% and 21%. The use of the storage unit (accumulator) allowed the dropping of the electric energy input.

Sangamithra *et al.* (2014) reported that the basic function of a solar dryer is to raise the vapor pressure of moisture found inside the product and increase the moisture-carrying capacity of the dehydrated air by decreasing its relative humidity. **Phadke *et al.* (2015)** reported that indirect solar dryer is advised for products that are photosensitive since it also protects product quality by shielding it from the sun. However, compared to a direct dryer, this one has the highest initial cost and requires more care.

The challenge in solar dryer the low values of efficiency because the weak of coefficient of thermal conductivity of air. Therefore, the aim of this study is improve the efficiency of solar dryer. So, **the objectives of this study were:**

(a) Developed and designed an indirect-type solar dryer experimental setup.

(b) Compared between solar dryers with and without PCM.

(c) Study the most appropriate operational factors during drying process to obtain the best quality of the dried product.

(d) Studied the effect of drying process on onion slices.

2. Materials and Methods:

The main experiments were carried out during the period from 1th until 12th of August 2023 at Farskour, Damietta Governorate, to investigate the use of solar energy as a source of dehydration onions. All experiments were conducted using a developed and normal solar dryers.

2.1. MATERIALS:

2.1.1. Solar dryer set-up:

The two solar dryers were designed and built in the Farskour area of Damietta, Egypt, to dry onion slices. The latitude and longitude angles for the precise locution are 31.25° N and 31.73° E, respectively. The dehydration unit is made up of a dehydration chamber that is connected to a solar collector. The experimental set-up's drying unit schematic diagram is displayed in Figure 1, with the component specifics listed below:

2.1.1.1. The two solar air collector:

The gross solar collector dimension is (125 cm length, 80 cm width, and 10 cm height). The solar air heater consists of a V-corrugated absorption plate coated with matte black paint, an acrylic cover, and insulation at the bottom. V-Shape corrugated (23 in number) absorber of 1.5 m^2 area was made from 0.5 mm thick aluminum sheet. A rectangular box for collector was made from a wooden frame of 1 cm thick. The air was permitted to flow through the space between the absorber and acrylic in a vertical direction to the V-shaped corrugation. A fiber glass wool (24 kg/m^3) with thicknesses of 2.5 cm and a thermal conductivity of 0.045 W/m.°C were used to insulate the bottom of the collector. To minimize the reflection of radiation and reduce the heat loss by convection, a clear transparent plastic (acrylic) (emissivity and transmission coefficients are respectively, 90% and 92%) was situated to cover the solar collector and fixed on rectangular box frame at a distance of 4 cm above the absorber as illustrated in Fig. 1 (b). The acrylic was fitted to rectangular frame with sponge rubber or silicone.

The second collector for the developed dryer (dryer B) has the same specifications as the collector for the normal dryer (dryer A), except that it is equipped with a rectangle of galvanized sheet with the same dimensions as the solar collector and a height of 5cm, and the absorbent surface is attached to it from above. 20 kg of paraffin wax is present inside. The absorbent surface was also sprayed with matte black in addition to nanotechnology (copper oxide).

The solar collector was angled towards the south and slanted at a tilt angle of β = 17.75°, determined using the following formula:

β = Latitude angle (Φ) – solar declination angle (δ), (°) ………….. **(1)**

Where: Φ = Latitude angle at Farskour district, Damietta is 31.25°N.

δ = Solar declination angle (°), for the average day of August is then,

$\delta = 23.45 \sin[0.9863 (284 + n)] = 13.5°$

n = number of the day from the first of January, 228 for August.

Therefore, the optimums tilt angle (β) for a fixed solar collector at Farskour zone, Damietta in August = 31.25 – 13.5 = 17.75°

2.1.1.2. Drying chamber

The two drying chambers were constructed from wooden cubes with 80 cm sides. Four trays were stacked at distances of 15 cm apart. Each tray's 80 cm x 70 cm wooden frame has a stainless steel wire screen with a 0.5 cm mesh to allow dehydration to occur throughout it and is fixed inside the drying chamber. The collector's output air goes into the bottom drying chamber. After that, it passes through the dehydration material in an upward direction. With the exception of the top, all walls of the chamber were insulated with 2.5 cm of thick glass wool to reduce heat loss to the surrounding air and avoid solar radiation absorption, particularly during the dehydration processes. The dehydration room was equipped with a chimney to exhaust waste air, which was covered to keep outside air out when the dehydration processes were completed. The height of the chimney was 30 cm. The exhaust fan (Type VF3020R CASTLE) with a power (P) of 250 W was fixed in the chimney and sucked drying air from the dehydration chamber to the outside. The dehydration chamber was fixed on an iron platform with sides of 80 cm.

2.1.2. Sample preparation:

Onions were hand-peeled and sliced (2, 4, and 6 mm thick) at a right angle to the vertical axis with the help of a hand-operated slicing machine. The slices were brined by steeping in a 5% NaCl solution for 10 min to prevent browning. After draining the solution, the surface water was removed by filter paper. The initial moisture content of the onion sample was determined by the oven method. About 4 kg of onion slices were loaded in a single layer in all four trays of the dehydration chamber equally.

2.1.3. Measuring Instrumentation:

2.1.3.1. Solar intensity:

Using the American Society of Heating, Refrigerating, and Air-Conditioning Engineers' modified model **(ASHRAE, 1993)**, the total average hourly solar radiation flux incident on the horizontal and slanted surface was computed theoretically.

2.1.3.2. Air flow rate measurement:

The air flow rate (m^3/s) was measured by Digital anemometer (+/-2% +0.5 m/s accuracy) (TETANO1, Model: H12A-B58102).

2.1.3.3. Temperature and Relative humidity measurement:

The data logger system (PPI Make) with an accuracy of ± 0.25% is used to detect temperature and relative humidity at various locations. From 8:00 AM to 6:00 PM, temperature data were taken on an hourly basis. As seen in Fig. 1(a), data loggers were positioned at the collector's inlet and outlet (Tin, Tout), outdoors to measure the surrounding temperature (T_{amb}), and immediately following each tray in the dehydration chamber (T_{d1}, T_{d2}, T_{d3}, T_{d4}) The temperatures of the drying air in each tray were measured, and its average value, $Td_{a\ (av)}$, was obtained.

2.1.3.4. Moisture content measurement:

To find the amount of moisture in dried and fresh onion slices both before and after dehydration processes, samples were weighed and dried using an electric oven and an electric equilibrium. The SF-400 electric equilibrium has a 10 kg capacity and an accuracy of ± 0.1g.

2.٢. METHOD:

At the beginning of each experimental run, the average initial moisture content of onion at different onion slices (2, 4, and 6 mm) was determined using two distinct weights of each representative sample. Weighing the samples was done when they were still fresh, and after being dried for a full hour at 130°C in an electric oven, the dried products were measured once more. The acquired data demonstrated that the typical starting moisture content was 85% w.b. The drying system was not humidified at night, and each dryer's air input and output ducts were conveniently caped.

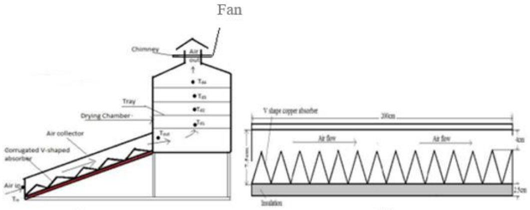


Fig: 1 (a) Schematic view of experimental setup; (b) Solar flat plat collector.

The samples of labeled onion slices were weighed at the beginning of each dehydration run and then every two hours until the samples reached a consistent weight. The ultimate moisture content of the dried onion slices was computed using this data. For every experimental run, the actual and total drying times, as well as the amount of moisture removed from onion slices, were computed. The drying rate of an onion slice is one gram of moisture eliminated every hour (g moisture removed/h). It was calculated by dividing the amount of moisture removed from the onion slices during the drying process by the actual drying time.

2.3. MEASUREMENTS AND DETERMINATIONS:

The evaluation of the performance of the collector efficiency and dryer efficiency was based on the following indicators:

2.3.1. The solar collector's thermal efficiency (η_C):

The solar air collector's thermal efficiency is the ratio of useful heat gain by the collector to the energy incident in the plane of the collector. It was computed using the following equation **Fudholi *et al.*, (2014)**

$$\eta_C = Q_{us} / q_{av} = [m\ C_p\ (T_{ao} - T_{ai})] / (I_T \times A_C),\ (\%) \quad \ldots\ldots (2)$$

The solar air collector's thermal efficiency is the ratio of useful heat gain by the collector to the energy incident in the plane of the collector. It was computed using the following equation **Fudholi *et al.*, (2014):**

$$m_a = A_h \rho_a v, \ (kg\ s^{-1}) \quad (3)$$

Where: A_h, is the surface area of the circular hole (outlet point) in m^2, ρ_a, is the density of dehydration air in kg/m^3, and v is the speed of dehydration air through the solar dryer in m/s.

2.3.2. The thermal efficiency of the dryer (η_D):

The dryer's thermal efficiency is the ratio of the energy used for moisture evaporation to the energy input to the dehydration system. It is calculated as **Banout *et al*. (2010):**

$$\eta_D = (DR \times H_{fg}) / ((I_T \times A_{SC}) + W_B) \quad (4)$$

Where:

DR is the drying rate (g/s).

H_{fg} is the latent heat of the vaporization of water (kJ/kg).

W_B is the electrical energy consumed by the blower.

2.3.3. Specific energy consumption (SEC):

Specific energy consumption (SEC) is the measure of the energy used to remove 1 kg of water in dehydration process. The specific energy consumption of the solar dehydration system was calculated using the following equations **Yahiya *et al*. (2017)**:

2.3.4. Drying Kinetics Analysis:

The moisture content of onion slices was calculated by two methods, such as wet and dry, using the following equations **Yahiya (2016)**:

The moisture content on a wet basis was calculated as follow:

$$M_{wb} = (m_w - m_d)/m_w \quad (5)$$

The moisture content on a dry basis was calculated as follow:

$$M_{db} = (m_w - m_d)/m_d \quad (6)$$

Where,

m_w = Initial weight of the sample, g

m_d = Final weight of the sample, g

The dehydration rate is the mass of water evaporated from the onion slices per unit time. It was calculated using the following equation **Kooli *et al.* (2007)**:

$$DR = m_{water}/t \quad (7)$$

Where m_{water} is the mass of water evaporated and t is dehydration time.

The mass of the water evaporated (m_{water}) from the onion slices was calculated using the following equation **Yahiya (2016)**:

$$m_{water} = m_{wetos} (M_{wb,i} - M_{wb,f}) / (100\ M_{wb,f}) \quad (8)$$

Where m_{wetos} is initial mass of onion slices, $M_{wb,i}$ is initial moisture content on wet basis and $M_{wb,f}$ is final moisture content on the wet basis.

3. RESULTS AND DISCUSSION

The following will be discussed: the estimation of solar radiation as well as the impact of various factors on the performance of solar collectors.

3.1. Calculated Parameters:

3.1.1. Position of the Sun:

Several angles can be used to characterize the sun's location in relation to a plane of any given orientation at any given moment **Duffie and Beckman (1991).**

3.2. Average hourly incident total solar radiation:

The hourly average total solar radiations incident on the horizontal and tilted surfaces (17.75°) were estimated and the results were illustrated in Fig. (2).The results indicated that, the hourly average total solar radiations incident on the solar collector surface almost clarified the same trend of that incident on the horizontal surface, while, the maximum values occurred at 12:00 noon. The daily average total solar radiations flux incident on the tilted surface was 8.98 kW.h/m^2.day. Meanwhile, the daily average total solar radiation incident on the horizontal plane was 8.11 kW.h/m^2.day. Consequently, the tilted surface of the solar collector inclined with an optimum tilt angle at noon (1٧.75º) for August month increased the solar energy by 10.73%, because the tilt angle causes the beam-radiation to be perpendicular on the collectors' surfaces at and around noon.

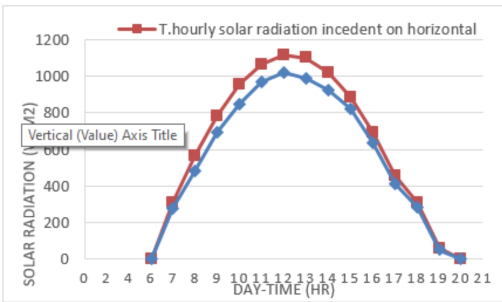


Fig. (2): Estimated value of average solar radiation of Farskour zone, Damietta, Egypt, at August, 2023.

3.3. Average hourly solar radiation available, absorbed and gained:

The results of estimating the hourly average solar radiation available, absorbed, and gained at two different air flow rates (2.8 and 1.8 m^3/min) are displayed in Fig. (3). Figure (3-a) According to the results, the tilted solar collector surface's daily average total solar energy available was 9.45 kW.h/day. In the meantime, the solar collector plate's daily average total solar energy absorption was 8.1 kW.h/day with an absorption efficiency of 85.71%. Nonetheless, the results indicated that the hourly average total useful energy gained (q_{us}) was directly affected by several factors, like: solar intensity (I), the difference between the inlet and outlet temperatures of the solar collector, and the mass of air flow rates (m). The results showed that the air's hourly total average useful heat energy with an air flow rate of 2.8 m^3/min was comparatively higher than with an air flow rate of 1.8 m3/min, since it was 7.41 KW.h/day and 6.57 KW.h/day for both air flow rates, respectively, for dryer B. From Fig. (3-b) The results showed that the average daily total solar energy available on the tilted solar collector surface was 9.45 KW.h/day. In the meantime, the solar collector plate's daily average total solar energy absorption was 7.57 KW.h/day with absorption efficiency of 80.1%. Nonetheless, The results showed that the air's hourly total average useful heat energy with air flow rates of 2.8 m^3/min was comparatively higher than that with air flow rates of 1.8 m^3/min, since it was 6.47 KW.h/day and 5.66 KW.h/day for both air flow rates, respectively, for dryer A. The highest possible value of the average hourly useful energy gained is attributed to the highest solar intensity, and the largest temperature difference between the input and output air was reached at 12 noon.

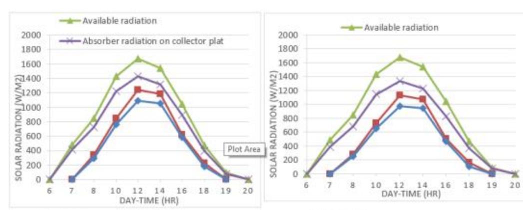
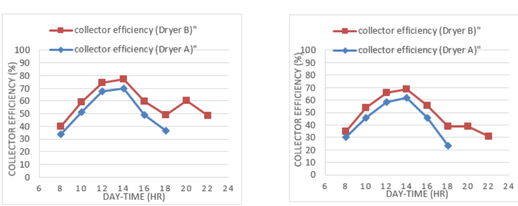


Fig. (3): Estimated values of average hourly solar radiation on the solar collector of Farskour zone, Damietta, Egypt, at August 2023.

3.4. Average hourly solar collector's thermal efficiency:

The solar collector's thermal efficiency at two dryers (dryer B and dryer A) was calculated, and the results are shown in Fig. (4).In Fig. (4-a) The results showed that the hourly average thermal efficiency of the solar collector almost clarified the same trend of the useful energy gained, where the extreme value occurred at 2 pm. The results showed that the hourly average solar collector's thermal efficiency tilted at the optimum angle with the developed dryer (dryer B) was 58.49%, which is comparatively higher than that (51.28%) with the normal dryer (dryer A). Therefore, the solar collector with the developed dryer increased the average hourly overall solar collector's thermal efficiency by 14.1% as compared with that of the normal dryer for the higher air flow rate (2.8 m^3/min).

From Fig. (4-b) The results showed that the hourly average thermal efficiency of the solar collector almost clarified the same trend of the useful energy gained, where the extreme value occurred at 2 pm. The results showed that the hourly average solar collector's thermal efficiency tilted at the optimum angle with the developed dryer (dryer B) was 48.31%, which is comparatively higher than that (44.2%) with the normal dryer (dryer A). Therefore, the solar collector with the developed dryer increased the average hourly overall solar collector's thermal efficiency by 9.3% as compared with that of the normal dryer for the lower air flow rate (1.8 m^3/min).



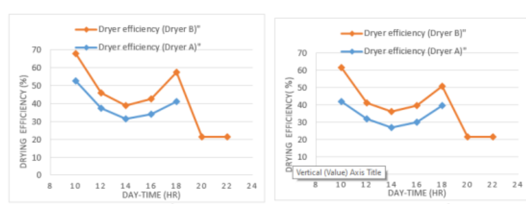
a) Air flow rate =2.8 m^3/min b) Air flow rate =1.8 m^3/min

Fig (4): Estimated value of average hourly solar collector thermal efficiency at different dryers of Farskour, Damietta, Egypt, at August 2023.

3.5. Average hourly efficiency of solar drying system:

The dryer's efficiency at two dryers (dryer B and dryer A) were calculated and the results are shown in Fig. (5). In fig. (5-a) The results illustrated that the hourly average dryer's efficiency with the developed dryer (dryer B) was 42.3%, which is comparatively higher than that (39.3%) with the normal dryer (dryer A). Therefore, the solar collector with the developed dryer increased the hourly average dryer's efficiency by 7.63% as compared with that of the normal dryer for the higher air flow rate (2.8 m^3/min).

From Fig. (5-b). The results showed that the hourly average dryer's efficiency with the developed dryer (dryer B) was 38.82%, which is comparatively higher than that (34.1%) with the normal dryer (dryer A). Therefore, the solar collector with the developed dryer increased the hourly average dryer's efficiency by 13.84% as compared with that of the normal dryer for the lower air flow rate (1.8 m^3/min). The obtained data is in agreement with that published by Yahiya, (2018).



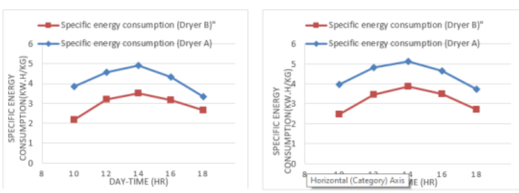
a) Air flow rate =2.8 m^3/min b) Air flow rate =1.8 m^3/min

Fig (5): Estimated values of average hourly Dryer efficiency at different dryers of Farskour, Damietta, Egypt, at August 2023.

3.6. Average hourly specific energy consumption:

The specific energy consumption at two dryers (dryer B and dryer A) was calculated and the results are shown in Fig. (6). In fig. (6-a) The results showed that the hourly average specific energy consumption with the developed dryer (dryer B) was 2.94 kW.h/kg, which is comparatively lower than that 4.19 kW.h/kg with the normal dryer (dryer A) Therefore, the solar collector with the developed dryer decreased the average hourly specific energy consumption by 42.52% as compared with that of the normal dryer for the higher air flow rate (2.8 m^3/min).

From Fig. (6) The results showed the hourly average specific energy consumption with the developed dryer (dryer B) was 3.19 kW.h/kg, which is comparatively lower than that (4.55 kW.h/kg) with the normal dryer (dryer A). Therefore, the solar collector with the developed dryer decreased the average hourly specific energy consumption by 42.63% as compared with that of the normal dryer for the lower air flow rate (1.8 m^3/min).



a) Air flow rate =2.8 m^3/min b) Air flow rate =1.8 m^3/min

Fig 6): Estimated values of average hourly Specific energy consumption at different dryers of Farskour, Damietta, Egypt, at August 2023.

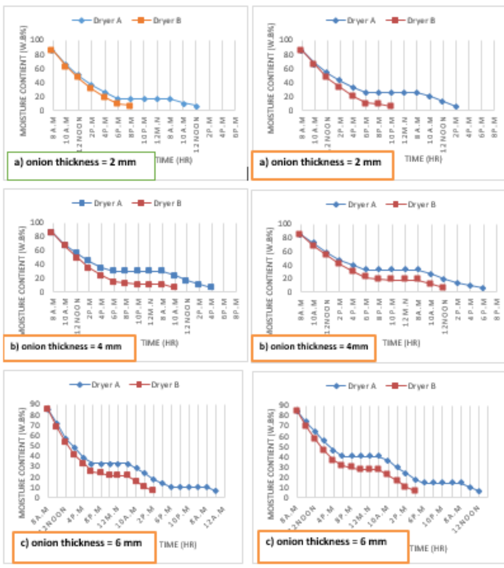
3.7. Drying Rate of Onion slices:

In general, the pace at which moisture evaporates during the dehydration processes is critical because it influences the changes in the qualities of the product. Three distinct onion slice thicknesses, two air flow rates, and two indirect-type dryers were investigated. To evaluate their effect on the onion slices drying rate.

3.7.1. Effect of type of dryer on the drying rate:

Fig. (7-a) shows the moisture content of onion slices determined at three onion slices (2, 4, and 6 mm) for an air flow rate of 2.8 m^3/min. At the 2 mm thick onion slices (Fig. 7- a-a), the moisture content reached equilibrium after the total dehydration time of almost 12 and 28 h in the dryer B and dryer A, respectively. At the 4 mm onion slices (Fig. 7-a-b), the moisture content reached equilibrium after the total dehydration time of almost 26 and 32 h in the dryer B and dryer A. respectively. At 6 mm onion slices (Fig. 7-a-c), the moisture content reached equilibrium after the total dehydration time of almost 30 and 50 h in the dryer B and dryer A, respectively.

Fig. (7-b) shows the moisture content of onion slices determined at three onion slices (2, 4, and 6 mm) for an air flow rate of 1.8 m^3/min. At the 2 mm-thick onion slices (Fig. 7-b-a), the moisture content reached equilibrium after the total dehydration time of almost 14 and 30 h in the dryer B and dryer A, respectively. At the 4 mm onion slices (Fig. 7-b-b), the moisture content reached equilibrium after the total dehydration time of almost 28 and 34 h in the dryer B and dryer A.-1 respectively. At 6 mm onion slices (Fig. 7-b-c), the moisture content reached equilibrium after the total dehydration time of almost 32 and 52 h in dryer B and dryer A, respectively.



a) Air flow rate =2.8 m3/min b) Air flow rate =1.8m3/min

Fig. (7): Effect of type of dryer on the moisture content of onion slices at different thickness and different air flow rates.

3.7.2. The Drying rate:

To evaluate the drying rates of onion slices at different thicknesses and compare their trends, air flow rates, and type of dryer, the total and real duration of dehydration, as well as the moisture removed from the onion slices, were computed. These calculations are presented in Table (1). It is clear that the drying rate increased as the onion slice thickness decreased and the airflow rate increased. As a result, the 2-mm-thick onion slice layer dried fastest at both airflow rates, followed by the 4-mm and 6-mm-thick layers. The drying rate of 1 g of moisture from the onion slices (2, 4 and 6 mm-thick layers) with the airflow rate of 1.8 m^3/min was 240.28, 186.88, and 152.9 g/h, respectively, which was 16.46%, 12.3%, and 9.81% lower than the corresponding rate (279.83, 209.87, and 167.9 gm. of moisture removed/h) with an air flow rate of 2.8 m^3/min, respectively,for dryer B.

To evaluate the drying rates of onion slices at different thicknesses and compare their trends, air flow rates, and type of dryer, the total and real duration of dehydration, as well as the moisture removed from the onion slices, were computed. These calculations are presented in Table (2). It is clear that the drying rate increased as the onion slice thickness decreased and the airflow rate increased. As a result, the 2-mm-thick onion slice layer dried fastest at both airflow rates, followed by the 4-mm and 6-mm-thick layers. The drying rate of 1 g of moisture from the onion slices (2, 4, and 6 mm-thick layers) with the airflow rate of 1.8 m3/min was 210.25, 168.2, and 140.16 g/h, respectively, which was 13.67%, 10.9%, and 8.89% lower than the corresponding rate (239.85, 186.55, and 152.36 g of moisture removed/h) with air flow rates of 2.8 m^3/min, respectively, for dryer A.

Table (١): Drying time and drying rates of onion slices at various air flow rate and onion slices thickness for Dryer B.

Month	Air flow rate	Onion slice thickness(mm)	Drying time (hr.)		Onion slice weight (g)		Moisture removed	Drying rate
			Total	Actual	Initial	Final		
August	2.8	2	12	12	4000	642	3358	279.83
		4	26	16	4000	642	3358	209.87
		6	30	20	4000	642	3358	167.9
	1.8	2	14	14	4000	636	3364	240.28
		4	28	18	4000	636	3364	186.88
		6	32	22	4000	636	3364	152.9

Table (2): Drying time and drying rates of onion slices at various air flow rate and onion slices thickness for Dryer A.

Month	Air flow rate	Onion slice thickness(mm)	Drying time (hr)		Onion slice weight (g)		Moisture removed	Drying rate
			Total	Actual	Initial	Final		
August	2.8	2	28	14	4000	642	3358	239.85
		4	32	18	4000	642	3358	186.55
		6	50	22	4000	642	3358	152.63
	1.8	2	30	16	4000	636	3364	210.25
		4	34	20	4000	636	3364	168.2
		6	52	24	4000	636	3364	140.16

4.8. Effect of dehydration processes on the chemical composition of onions:

Table (3) shows the chemical composition of the onions, fresh and dehydrated. From The results, it is possible to see that some components are not influenced by the dehydration processes (fat, ash, soluble solids, and ph), whereas others are significantly influenced by this parameter (sugars and vitamin C). Total sugars contained in dried onion slices were also affected by the dehydration process in the two different dryers. Originates a degradation in sugars of about 19.11% (dry basis) for dryer B and 17.84% for dryer A. The percentage of total sugars contained in the fresh onions (47.95%) was decreased in dried onion slices and reached 30.11% and 28.84% for the two different dryers B and A, respectively. This behavior probably occurred because of the reduction in moisture content after the dehydrating process. Nevertheless, a reduction in the concentration of total sugars contained was observed during the dehydrating process.

The vitamin C content in the fresh onions (1820 mg/100g) was decreased in the dried onion slices and reached 135 mg/100g and ٨٩ mg/100g dry solids for the two different dryers B and A, respectively. These outcomes were expected since these components are the most influenced by the drying temperature: the sugars degrade by Millard and browning reactions, and vitamin C is known to be extremely sensitive to temperature. In fact, the difference between the vitamin C content of the fresh onion and the onion dehydrated is extremely high, thus indicating that drying greatly affects the vitamin C content.

Table (3) Chemical composition of onions, fresh and dried at dryers A and B.

	Fresh onion	dried onion (A)	Dried onion (B)
Fat (g/100g dry solids)	0.46	0.23	.32
Ash (g/100g dry solids)	3.11	4.81	4.95
PH	5.7	5.6	6.1
Total soluble solid %	9.9	40.1	47.39
Total sugars (g/100g dry solids)	47.95	28.84	30.11
Vitamin C (mg/100g dry solids)	1820	89	135

4. CONCLUSION:

The solar collector surface at the optimum tilt angle (17.75) increased the solar radiation incident on the horizontal surface by 10.73%. The developed dryer (Dryer B) increased the hourly average overall solar collector's thermal efficiency by 14.1% and 9.3% as compared with the normal dryer (Dryer A) at air flow rates of 2.8 m3/min and 1.8 m3/min, respectively. The developed dryer (Dryer B) increased the dryer's efficiency by 7.63% and 13.84% as compared with the normal dryer (Dryer A) at air flow rates of 2.8 m3/min and 1.8 m3/min, respectively. So that, the best results of onion slices drying appeared with the developed dryer, this is due to the development that was made on the dryer, which led to higher drying air temperatures in the developed dryer as a result of painting the absorbent surface with nanotechnology (copper oxide), and Nonetheless, to storing energy during the day via paraffin wax and emitting it at night, which led to an increase in the efficiency of both the solar collector and dryer. Using the developed dryer reduced drying time by approximately two hours. It was also noted that the nutritional value of onion slices dried using the developed dryer is higher than dried using a narmal dryer.

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The authors declare that they have no conflict of interest.

AUTHORS CONTRIBUTION

EL-Sharabasy, M. M. A.; EL- Darwesh, M. R., and Sameh A. EL-M. Khalifa developed the concept of the manuscript. Khalifa wrote the manuscript. All authors checked and confirmed the final revised manuscript.

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الملخص العربي

تطوير المجفف الشمسي الغير مباشر لتجفيف البصل تحت الظروف المصرية

سامح ابو المعاطي خليفه[١]، محب محمد انيس الشرباصي[١] ، محمد رمضان درويش[٢]

١ـ قسم هندسة النظم الزراعية و الحيوية – كلية الزراعة – جامعة دمياط - مصر.

٢ـ قسم المنشأت الزراعية و التحكم البيئي –جامعة طنطا- مصر.

تهدف هذه الدراسة الى تصميم واختبار مجففين من النوع الغير مباشرأحدهما مزود بشمع البرافين كمادة لتخزين الطاقة والسطح الممتص للمجمع الشمسي تم تعريجه ورشه بمادة نانو تكنولوجي (أكسيد النحاس) والآخر مجفف عادي حيث تم تعريج السطح الماص ورشه بلون اسود مط فقط وذلك تحت الظروف المناخية لمركز فارسكور بمحافظة دمياط والذي يقع عند خطي عرض ٢٥.٣١ شمالا و ٧٣.٣١ شرقا. كان السبب الأساسي لانتقاء نظم التجفيف الشمسي في تجفيف الحاصلات الزراعية أنها عملية إقتصادية، موفرة للوقت والطاقة وكذلك صديقة للبيئة. وقد استخدمت هذه الوحدة لتجفيف شرائح البصل (قطاعات عرضية) الذي يعتبر من المحاصيل الرئيسية والتصديرية في مصر. تتكون الوحدة من جزئيين رئيسيين هما المجمع الشمسي الذي يقوم بتسخين الهواء الجوي والثاني هوغرفة التجفيف حيث تم تزويدها بصواني تجفيف مصنوعة من هيكل خشبي وشباك سلكية من الصلب لكي تسمح للهواء الساخن بالعبورعلى المواد المراد تجفيفها متماثلة وبالتالي زيادة معدل التجفيف.وقد أجريت تجارب تجفيف شرائح البصل لكلا المجففين لملاحظة وتحديد مدى استجابة نظام التجفيف الشمسي المناسب لمستويين من معدل سريان الهواء (١,٨م^{٣}/دقيقة و ٢,٨ م^{٣}/دقيقة) و ثلاثة سماكات مختلفة لشرائح البصل (٢، ٤، ٦ مم) عند دورة من درجات الحرارة اليومية خلال ساعات النهارمن (٢٧م° - ٤٤ م°) خلال شهر اغسطس لكلا من المجففين.

و قد اوضحت نتائج الدراسة ما يلي :

١- المحتوى الرطوبي الابتدائي لشرائح البصل ٨٥% على اساس رطب.

٢- تأثرت درجة حرارة الهواء الساخن الخارج من المجمع الشمسي بمعدل سريان الهواء حيث كان المتوسط اليومي لدورتي درجات حرارة هواء التجفيف اثناء النهار ٣٤ – ٦٤ م°، ٣٥ – ٧٣ م° عند معدلي سريان الهواء ١,٨م^{٣}/دقيقة ، ٢,٨ م^{٣}/دقيقة على الترتيب للمجفف المطور و ٣٣ – ٦٢ م°، ٣٤– ٧٠ م° عند معدلي سريان الهواء ١,٨م^{٣}/دقيقة ، ٢,٨ م^{٣}/دقيقة على الترتيب للمجفف العادي.

٣- كان متوسط الساعة للاشعاع الشمسي ٨١١,٨١ وات/ م٢ و كان متوسط الساعة لدرجة حرارة الهواء خارج المجفف ٣٤,٥ م° وداخل المجفف ٥١ م° و ٤٦ م° عند معدلي سريان الهواء ١,٨م^{٣}/دقيقة ، ٢,٨ م^{٣}/دقيقة على الترتيب للمجفف المطور و ٤٤,٥ م° و ٤٩ م° داخل المجفف العادي عند نفس معدلي تدفق الهواء على الترتيب.

٤- أدى استخدام المجمع الشمسي بزاوية ميل مثالية قدرها ١٧,٧٥° إلى زيادة سقوط الإشعاع الشمسي بمقدار ١٠,٧٣% عن الأفقي.

٥- كان المتوسط الكلي للكفاءة الحرارية في اليوم للمجمع الشمسي ٥١,٢٨ %، ٥٨,٤٩ % عند المجففين أ ، ب على الترتيب حيث أدى استخدام المجفف المطور (المجفف ب) إلى زيادة كفاءة المجمع الشمسي بنسبة ١٤,١ % عند معدل سريان الهواء ٢,٨م^{٣}/دقيقة و ٤٤,٢%، ٤٨,٣١ % عند المجففين أ ، ب على الترتيب حيث ادى استخدام المجفف المطور (المجفف ب) إلى زيادة كفاءة المجمع الشمسي بنسبة ٩,٢٩ % عند معدل سريان الهواء ١,٨م^{٣}/دقيقة.

٦- كان المتوسط الكلي للكفاءة الحرارية في اليوم للمجفف ٣٩,٣ %، ٤٢,٣ % عند المجففين أ ، ب على الترتيب حيث ادى استخدام المجفف المطور (المجفف ب) الى زيادة كفاءة المجفف بنسبة ٧,٦٣ % عند معدل سريان الهواء ٢,٨م^{٣}/دقيقة و ٣٤,١%، ٣٨,٨٢ % حيث ادى استخدام المجفف المطور (المجفف ب) الى زيادة كفاءة المجفف بنسبة ١٣,٨٤ % عند معدل سريان الهواء ١,٨م^{٣}/دقيقة.

٧- تأثر المحتوى الرطوبي لشرائح البصل بسمك شرائح البصل و معدل سريان الهواء عند دورتين من درجات حرارة التجفيف اثناء النهار (٣٤ – ٦٤ م°، ٣٥ – ٧٣ م°) ، (٣٣ – ٦٢ م°، ٣٤– ٧٠ م°) و عموما فان زيادة معدل سريان الهواء او نقص سمك شريحة البصل او كليهما معا أدى إلى تقليل الوقت المطلوب للتجفيف.

٨- تراوح المحتوى الرطوبي النهائي لشرائح البصل المجففة من ٥,٦٦ الى ٦,٥٤ % على أساس رطب معتمدا على دورة درجات حرارة هواء التجفيف.

٩- إن استخدام المجفف المطور قلل من زمن التجفيف بمقدار ساعتين تقريبا. كما انه لوحظ أن القيمة الغذائية لشرائح البصل المجففة باستخدام المجفف المطور أعلى من المجففة باستخدام المجفف العادي.