DESIGN NEW PROTOTYPE OFAN INDIRECT SOLAR- ELECTRICAL DRYER TO DRY WHITE ONIONS SLICES

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ABSTRACT

In the present research, a new specific model of an indirect solar–electrical dryer for onions slices was designed and constructed at a Zagazig City , Sharkia Governorate, Egypt. Solar dryer consists of solar flat plate air collector with V- corriugated absorption plate. The total area of the collector is 1.75 m^2. The size of the drying cabinet is (1.5 × 0.50 × 1) m (height, width and depth). An experiment was conducted to study drying of onions slices 5 and 10 mm. The qualitative analysis for drying of onions slices of 5 mm under three air velocities (1.5,2.2 and 3) m/s, showed that moisture content was reduced from (669.23db to 6.95, 8.69 and 14.41db), (4.27,5.26 and 9.89db) and (2.04, 3.09 and7.52db) for($Tray_1$, $Tray_2$, $Tray_3$) while it were (19.33,26.90 and 33.51db), (14.41, 21.35 and 27.71db) and (9.89, 16.27 and 21.95db) for onions slices 10 mm respectiviely.The average moisture content of open sun dry were 20.60 and 50.95 db for onions slices of 5and10 mm. The average percentage thermal efficiency for the collector was found to be 33.03, 49.96 and 65.45 % while it were 21.37,15.43 and 10.29% of the dryer for air speed 1.5,2.2 and 3 m/s,, respectiviely.The average percentage value of the collector 34.07,37.59 and 42.69% while it were be24.82, 32.55and 41.85% for the dryer at air velocities were1.5,2.2 and 3 m/s, respectiviely. In order to estimate and select the suitable form of solar drying curves, five different mathematical models, were compared according to their coefficient of determination R^2, MBE, RMSE, %E and chi square X^2 to estimate experimental drying curves. The Modified page model in this condition proved to be the best for predicting drying behavior of onions slices of 5 and10 mm with (R^2 = 0.9961and0.9899) and (X^2 = 0.000148 and0.000591). The effective moisture diffusivity (Deff) was obtained using Fick's diffusion equation and its value varied from 1.72958× 10^{-9} to 2.37261× 10^{-9} m^2/s and 4.31037× 10^{-9} to 5.61732× 10^{-9} m^2/s while the value of activation energy ranged from 23.49 to 29.82 kJ/mol k and 16.09 to 18.01 kJ/mol k for onions slices of 5and10 mm.

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Finally an economic evaluation was calculated using the criterion of payback period which is found very small 1.05 years compared to the life of the dryer 25 years.

Key words: *Solar drying, Drying models , Onions, Effective diffusivity, activation energy, efficiency, effectivness, payback period.*

INTRODUCTION

Onion, is considered as one of the most important as a vegetable crops in all countries as they are considered food and culinary value.The problems of producing and storing onions led to tendency to drying it using solar dryers as alternative sources to conserve the environment. **Can (2000)** indicated that drying process takes place in two stages. first happens on the surface of drying material with a constant drying rate and is like to vaporization of water into the ambient air while the second takes place by decreasing drying rate.

Sharma et al.,(2005) developed an infrared dryer for drying onion slices at air temperatures of 35, 40 and 45 °C and air velocities of 1.0, 1.25 and 1.5 m/s. Drying rate increased with increasing air temperature and velocity and thus reduced the drying time. Page s model had a higher correlation coefficient and low chi-square value and thus predicted drying behavior of the onion slices more accurately.

Pankaj (2006) carried out some drying experiments on onion slices (6mm thickness) by using infrared convective drying. The average effective moisture diffusivity of onion slices ranged between 2514×10^{-10} and 3233×10^{-10} m^2/s while the activation energy ranged between5.06 and 10.63 ***kJ/mol k*** that indicated to decrease in energy of activation.

Thin layer drying equations are used to estimate the drying time for several products and also to generalise the drying curves. Drying kinetics is greatly affected by the air velocity, air temperature, material thickness, and others (**Erenturk and Erenturk 2007**).

Active solar dryers are designed incorporating external means, such as fans or pumps, for moving the solar energy in the form of heated air from the collector area to the drying beds. An advanced and alternative method to the traditional techniques is greenhouse drying in which the product is placed in trays receiving solar radiation through the plastic cover, while moisture is removed by natural convection or forced air flow (**Kumar and Tiwari, 2007**).

Physical and thermal properties of agricultural products, such as the heat and mass transfer, moisture diffusion, and activation energy, are required for the ideal dryer design (**Aghbashlo et al., 2008**).

Drying is the oldest and most widely used primary method of food preservation. In general, it is a means of removal of water from the material. The purpose of drying food products is to allow longer periods of storage with minimized packaging requirements, reduce shipping weights, and preserve seasonal plants and make them available to consumers during the whole year (**Apar et al., 2009**).

(Mota et al., **2010**) study the drying of onions in terms of drying kinetics, which was evaluated at 30, 50 and 60 °C.Three empirical models tested the present work were (Newton, Modified Page and Logarithmic) all describe relatively well the dehydration kinetics at the three temperatures analyzed. From the results obtained the diffusivities, which range between 3.33×10^{-9} m^2/s at 30 ◦C and 8.55×10^{-9} m^2/s at 60°C.

El Mesery and Mwithiga (2012) investigated The drying behavior of onion slices by using two types of dryers,vertical and horizontal convective.Drying air temperatures were 50, 60 and 70°C, while air velocities were set at 0.5, 1.0 and 2.0 m/s, they found the Page model was the best in describing the drying behavior of onion slices and the drying time less in case of the horizontal convective comparison with vertical convective while onion slices dried at higher temperatures had higher rehydration ratios.

Edoun et al., (2013) reported that drying process take place in closed equipment improved the quality of the final product.

Vijay et al., (2013) reviewed various types of flat plate solar collectors with various applications. They also discussed the design parameters, construction, arrangement, and sizing of various solar collectors and their performances.

To obtain the highest solar intensity on the collector, in summer, the inclination angle of the reflector was maintained at 45° with respect to the horizontal axis **(Tabaei and Ameri, 2015)**.

Mahmoud et al.,(2018). Found that a model is considered more suitable the higher values of R^2 and the lower the values of x^2, RMSE and E%.

The main contribution of this paper to prduce drying onion slices(5 and10 mm) by using the solar drying cabinet under various tempratues of ambient air and air flow rates .This manuscript focus on development a suitable drying mathematical model of thin layer forced and natural solar for describing the drying process; in addition to compute effective moisture diffusivity and activation energy of samples. efficiency and effectivness of the solar collector and dryer under three various air mass flow rates were also determined.

MATERIALS AND METHODS

The drying process was conducted by using the solar drying cabinet in late summer during the month of Sebtemper, 2018 in Zagazig City, Sharkia Governorate, Egypt. (longitude (Φ) =30° 34’ 00” N and latitude (λ) =31° 30’ 00” E). The drying of apricot was examined in the indirect forced convection solar– electrical constructed and installed at a the roof of house in Zagazig City, Sharkia Governorate, Egypt. The experiments started at 8:00 am and terminated at 5:00 pm. It was installed in an environment with the relative air humidity of 27~59%, ambient air speed of 0.7 ~ 4.8 m/s, and ambient air temperature varying from 26 to 37°C under solar radiation changing between 40 and 852 W/m^2. During the experiments, the ambient temperature, relative humidity, and inlet and outlet temperatures of air in the solar collector and dryer chamber were recorded. Solar collector was installed on a raised far from the shade of trees or buildings during the whole duration of the system trial. A schematic diagram of the dryer used in the experiments is shown in Figs. (1 and 2). Dryer system consists of the following parts.

1- Corriugated plate solar collector:-

The solar air collector has an area of 1.5 m^2 is inclined at an angle of 19° 30’ 00” N (latitude of Zagazig city) with the horizontal facing south all the time and use of sheet metal absorption zigzagging from galvanized sheet thickness of 0.001 m and 55^o goffer angle and height of 0.05 m from the basis of plate and painted matte black not shiny to absorb most of the incident solar radiation. The top losses are minimized by placing a glass cover of 0.005 m thickness over the top of the galvanized metal sheets. The solar air collector made from alminum frame like a box, sides and bottom were insulated by a layer of fiber glasses sandwiched between two parallel galvanized metal sheets with a thickness of 0.0 25 m from the sides and 0.05 m from the bottom. The collector walls of dimensions of 1.5 × 1 × 0.30 m (height, width and depth).There is a distance of 0.20 m as air gap between the glasses cover and absorbing plate. Ambient air enter the collector from one opening in the front of collector air so that the air was drawn under the glass sheet and the absorber.hot air exit from four openings back collector throught plastic tubes isolated to drying cabinet.

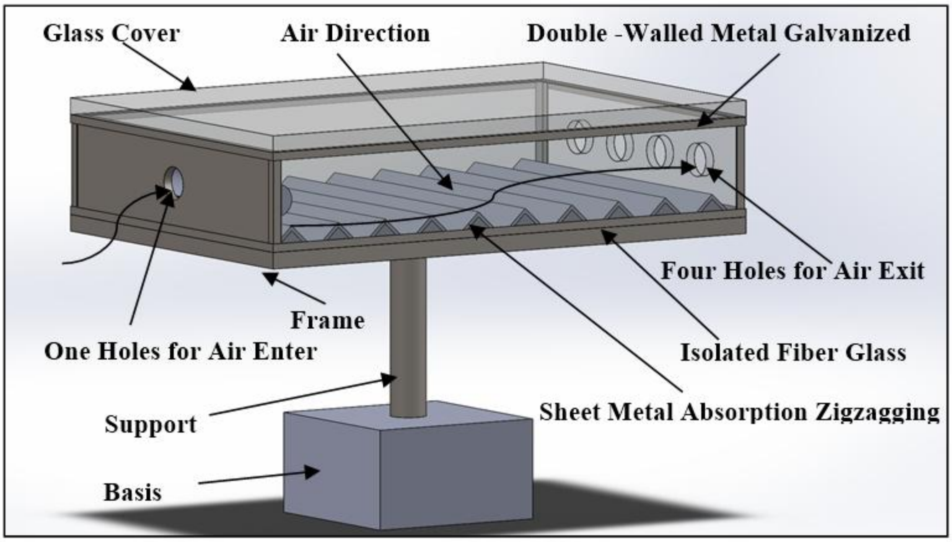

Fig. (1): A Schematic view of solar collector components.

2- drying cabinet:-

The drying chamber made from alminum frame like box, sides and bottom were insulated by a layer of fiber glasses sandwiched between two parallel galvanized metal sheets with a thickness 0.0 25 m from the sides and 0.05 m from the bottom such as collector with walls of dimension (1.5 × 0.50 × 1) m (height, width and depth) cabinet including four perforated wire mesh trays and double door easy to open and closed to putting the product. Cabinet provided with two electrical exhusted fan with diameter 0.15 m model MH-15G power in put 16 Watt, running at 1560 rpm/minute controlled manually by electrical resistance to change air velocity. and air flow rate at 1.5,2.2 and 3 m^3/s.

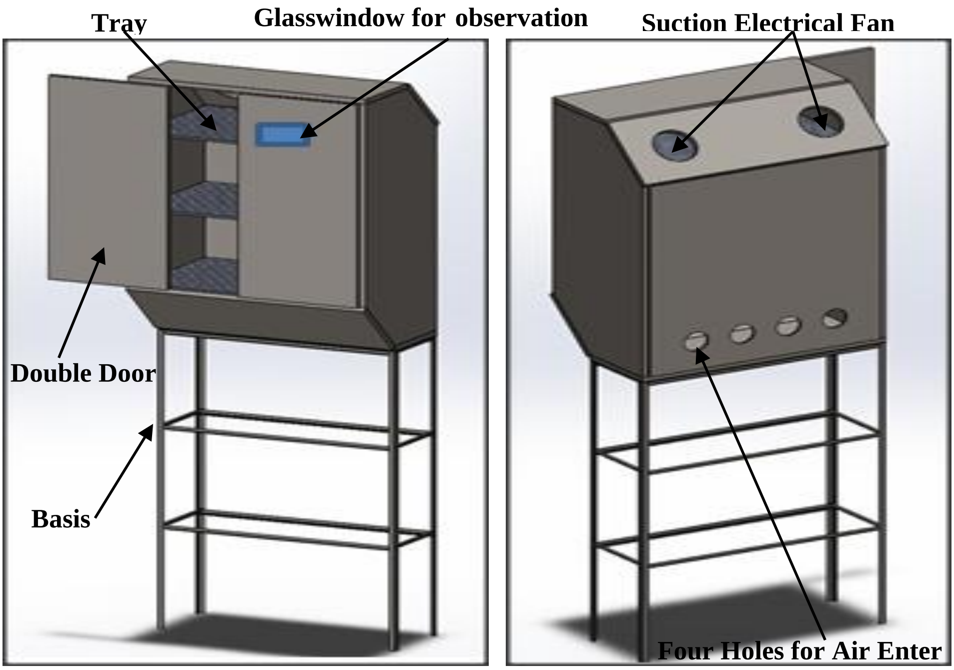

Fig. (2): A Schematic view of drying cabinet components.

3- Iron installation basis:-

Iron basis used to putting solar collector and drying cabinet on it .The basis allow to a solar collector rotating around the axis of its fixation to change the angle of inclination as seasion and the city location.

4- Sample preparation:-

Locally available white onion was used in the present study purchered from market. About 100 g of onion slices (5 and10 ±0.025 mm) were prepared by regulate the opening of the slicer knife with a vernier calliper.

METHDOLOGY:-

White onion slices were dryed by two ways solar drying, the first way was forced convection in the solar assisted dryer, about 100 g of onions slices were uniformly distributed on each tray and kept inside the dryer while the second natural convection, 100 g of onions slices spread on the ground and left to natural drying by open sun-light.The initial moisture content of the onions slices were 87% wet basis (wb) and determined by using electric balance before and after drying. Three replicates about 100 g of onion slices were placed on electrical oven at 78°C for 24 h according to the Association of Official Analytical (**AOAC, 2005 and Sultana et al.,2009)**. The drying air enters from the bottom of our prototype dryer and moves up through the material loaded in different trays and leaves forced by a fan from the top to the surrounding. study was done in a somewhat varius air temperature and three air velocity of (1.5,2.2 and 3m/s), in the samples mass were noted every 30 minute until the samples reached to final the percent of moisture ratio terminated the day 5.00:PM. Average temperature of the three trays were recorded at each fan speed. Moisture ratio (MR) was calculated from the obtained experimental moisture content values.

1- Moisture ratio:-It can be calculated as follows: **(Midilli, 2001).**

$$MR = \frac{(Mt - Me)}{(Mo - Me)} = \frac{Mt}{Mo} \longrightarrow (1)$$

Thin-layer drying models used for mathematical of drying of onion slices:- The experimental drying data were tested to find the most suitable model among five different models defining drying process set by a number of authors (Table 1).

Table (1) Mathematical models used to describe the thin-layer drying curve.

No.	Model name	Analytical expression	Reference
1	Lewis	$MR = \exp(-k_L\, t)$	Bruce (1985)
2	Page	$MR = \exp(-k_P\, t^n)$	Page (1949)
3	Modified page	$MR = \exp(-k_M\, t)^n$	White et al., (1981)
4	Modified page II	$MR = \exp(-k\,(t/L2)^n)$	Diamante and Munro (1991)
5	Henderson and Pabis	$MR = a\exp(-k_H t)$	Henderson and Pabis (1961)

The various constants in the tested models were determined using non-linear regression procedure using IBM SPSS software package (IBM SPSS version 22). The coefficient of determination (R^2), reduced chi-square (X^2),root mean square error (RMSE) and the average percentage error (E%) were used to inspect the good fitness of the selected mathematical models to the experimental data. A model is considered more suitable the higher values of R^2 and the lower the values of X^2, RMSE and E % (**Midilli and Kucuk, 2003; Akpinar et al., 2006)**.

The following equations were used to calculate the abovementioned parameters:

$$R^2 = 1- \left[\frac{\sum (MR_{Prd} - \sum MR_{Exp})}{\sum (\overline{MR}_{Prd} - \sum MR_{Exp})} \right] \longrightarrow (2)$$

$$\chi^2 = \frac{\sum (MR_{Exp} - MR_{Prd})^2}{N - n} \longrightarrow (3)$$

$$RMSE = \left[\frac{\sum (MR_{Prd} - \sum MR_{Exp})^2}{N} \right]^{½} \longrightarrow (4)$$

$$\% E = \frac{100}{N} \sum \frac{MR_{Exp} - MR_{Prd}}{MR_{Exp}} \longrightarrow (5)$$

Moisture diffusivity and activation energy:-

Fick's second law of unsteady state diffusion given in Eq.(6) where,the effective moisture diffusivity was calculated from a slope of a straight line by plotting experimental drying data in terms of ln (MR) versus drying time(**Crank, 1975**).

$$MR = \frac{Mt}{Mo} = \frac{8}{\pi^2} \exp \left[\frac{\pi^2 D_{eff}\, t}{4 L^2} \right] \longrightarrow (6)$$

The effective moisture diffusivity can be related with temperature by simple Arrhenius-type relationship:

$$D_{eff} = Do \exp \left[- \frac{Ea}{R\, T_{abs}} \right] \longrightarrow (7)$$

Solar collector and dryer calculation:-

1- The thermal collector efficiency ($\%\eta_C$):- collector efficiency is defined as the ratio of energy output of the collector to energy input (R. Ac) to the collector (J) and is calculated from the following mathematical formula (**Boughali et al.,2009**).

$$\%\eta_c = \frac{m. Cp . \Delta T}{R. Ac} \times 100 \longrightarrow (8)$$

R = solar radiation (W/m^2)

2- The thermal dryer efficiency ($\%\eta d$): - Expressed by the ratio of energy used to evaporate water in the product (Eu) to the energy provide to the air during drying (EA) plus energy of the fan (EF) in the following form (**Boughali et al.,2009**):

$$\%\eta_d = \frac{E_u}{E_A + E_F} \times 100 \longrightarrow (9)$$

The heat used to evaporate water in the product (Eu) is defined as:

$$E_u = m_e * L_e \longrightarrow (10)$$

The useful heat passed to the air (EF) is defined as:

$$E_A = ma * Cp * \Delta T \longrightarrow (11)$$

3-Collector effectiveness (% EC):- Collector effectiveness in the following form **(Ghoniem and Gamea 2014)**:

$$\% E_C = \frac{(T_{I\,in} - T_{I\,out})}{(Tc_{out} - T_{I\,in})} \times 100 \longrightarrow (12)$$

4-Dryer effectiveness (%E$_I$):- Dryer effectiveness was simplified as per the following relationship (**Ghoniem and Gamea, 2014**).

$$\% E_d = \frac{(Tc_{in} - T_{amb})}{(Tc_{out} - T_{amb})} \times 100 \longrightarrow (13)$$

5-- Rehydration ratio and coefficient of rehydration: The rehydration ratio was estimated by placing 10 g of samples with 1000 ml of boiling water about 5 minutes **(Maskan ,2001)**.

$$Rr = \frac{W_r}{W_d} \longrightarrow (14)$$

$$COR = \frac{W_r\,(100-M_i)}{W_d\,(100-M_f)} \longrightarrow (15)$$

Measuring Instruments Data.

"Weather station model PC-200. Was used for monitoring solar radiation (1 ~2000 W/m^2) with an accuracy of ± 5%.

Digital thermometer Model (TPM -10) series hand held Instrument. With a thermocouple was used for monitoring temperature with accuracy of ± 1 ^{o}C and at range (-50 ~ 110 ^{o}C) by reading liquid crystal display (LCD).

Digital Anemometer Model (GM816) series hand held Instrument. Used for measuring wind speed and temperature by reading liquid crystal display. Wind speed range (0 ~30 m/s).

Digital hygrometer-thermometer Model (ETI 810-155) series hand held Instrument. With a thermocouple was used for monitoring relative humidity at range (20 - 99 %) with an accuracy of ± 5%.

Electronic balance Model (SF-400) having an accuracy of 0.01 g with capacity 7 kg and the weight of samples were recorded on a LCD display.

Vernier caliper having a least count 0.025 mm.

Costs was calculated according to the following model:-

Based on the climatic conditions in Zagazig City which allow using the solar–electrical dryer almost all the year days (365 days). The costs and the main economic parameters based on the economic situation in Egypt are shown in table (2).

Table (2)Payback period of the solar dryer.

Dryer price	**12000 L.E**
Capacity of dryer	**6 kg**
Depreciation	**1000 L.E**
Life of dryer	**25 years**
Cost of maintenance	**1000 L.E**
Labor cost 20 × 180 year	**3600 L.E**
Cost of electrical consumption, L.E /year	**200 L.E**
Cost of raw onions 6 × 5 × 180	**5400 L.E**
Total cost	**10200 L.E**
Total income 180 × 1.2 × 100	**21600 L.E**
Net income	**11400 L.E**
Note 1US Dollar ≈ 18 L.E.	

Using this data, the payback period was calculated using the formula below (**Neufville, 1990**)

$$\text{Payback period} = \frac{\text{Initial Investment}}{\text{Annual Net Undiscounted Benefits}} \longrightarrow \quad (16)$$

The payback period is determined as the time required for the investment cost to equal the return.

RESULTS AND DISSCUSION

Practical trial for solar–electrical dryer under load.

(Figs. 3–5) show the trial run on electrical dryer extended to for three days in late summer season (18,19 and 20/9/2018) to test our electrical dryer. Designing and evaluation a thermal behavior of the solar collector and dryer device requirmentes knowledge an important parameter such as adata on the ambient air temperature, air speed, humidity of ambient air and solar radiation. The outlet air temperature which inlet the dryer is an important variable for drying operation; of the flat plate collector, it go up and down in the same direction as the solar radiation on this collector and increased by decreasing drying air velocity.

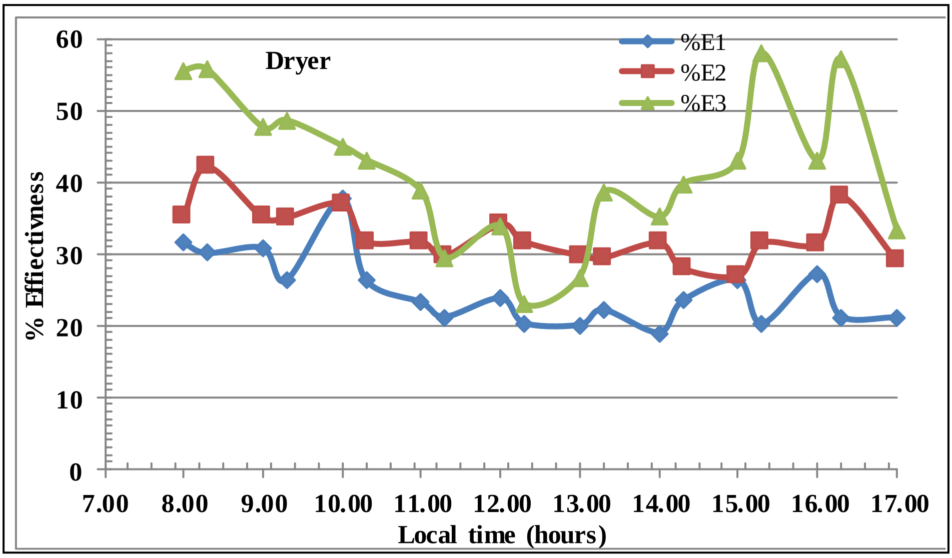

Fig. (3): Solar radiation and temperature variation of different elements of the collector on 18/9/2018

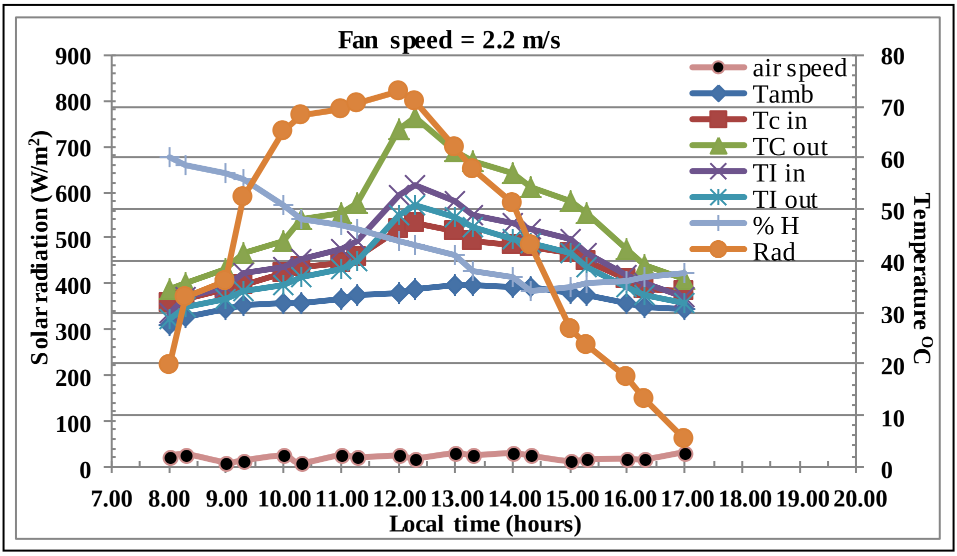

Fig. (4): Solar radiation and temperature variation of different elements of the collector on 19/9/2018.

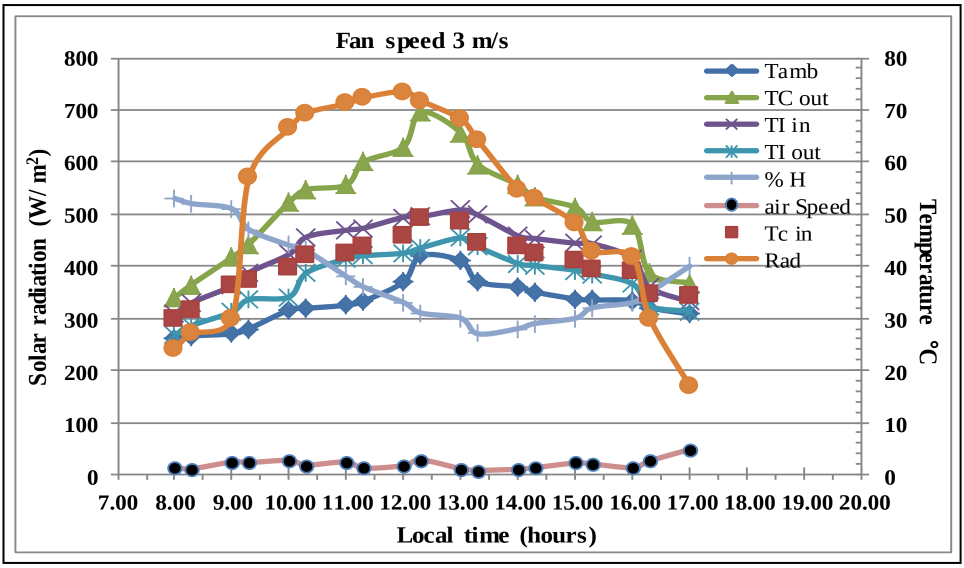

Fig. (5): Solar radiation and temperature variation of different elements of the collector on 20/9/2018.

experiments conducted on a solar–electrical dryer indicated that the maximum temperatureis achieved afternoon while the maximum radiation is reached at 12 noon. The moisture decrease inside the drying chamber

due to the circulation of the air, using the fan which allows having heat and mass exchange.The diffreance between input and output temperature were (1.9~19.9°C), (2.2~16°C) and (2.4~20.4°C) for air speeds of 1.5,2.2 and 3 m/s, on the practical trial as they depending on weather factors decreased and air velocity.its noticed that heat losses until heated air arrived to 29.09, 21.87 and 28.87 % until they reached to the dryer for air speed 1.5,2.2 and 3 m/s, as they decreased by increaseing air velocity and temperature.

Collector efficiency (%η):-

Figure (6). Pointing to the collector efficiency which increases with solar radiation increase until a limit where the efficiency tends to come down beyond this value. From the linear relationship between the velocity of air masse flow rate and the passage of local time,it observed that collector efficiency increases, rapidly at high velocities 3 m/s, collector efficiency increases with solar radiation increase until a limit where the efficiency tends to come down beyond this value and they were ranged from (10.33 to 44.92%),(26.65 to 65.28%) and (40.33 to 89.19%) at air speeds 1.5, 2.2 and 3 m/s, respectively so that velocities 3 m/s, is better compering with the others velocities. (**Kutscher et al.,1993**) noted that efficiency increase until for approach velocities greater than 5 m/s, then it constant beyond this value so our results agreement with previously studies.

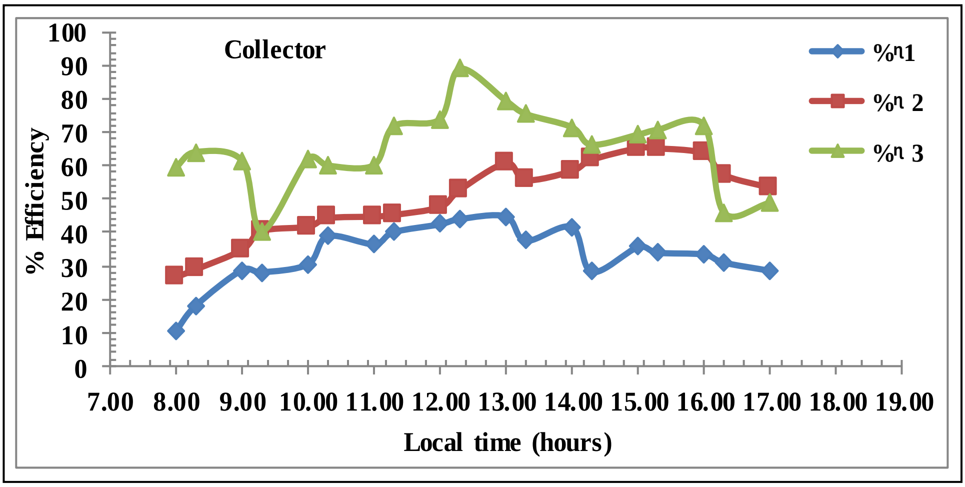

Fig. (6): Daily collector efficiency under different flow rates.

Collector effectiveness (EC %):-

The daily collector effectiveness is shown in Fig. **(7)**.The maximum and the minimum of collector effectiveness were ranged from 9.52 to 45.39% and from 27.97 to 51.72% while it was 26.08 to 63.26% at air

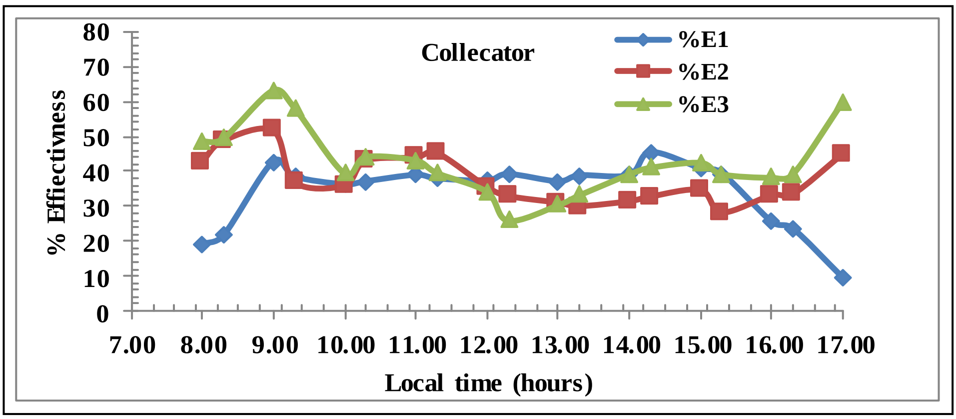

Fig. (7): Daily collector effectiveness diverse flow rates.

speed 1.5, 2.2 and 3 m/s, respectively. Solar collector effectiveness at different solar time starting 8.00 am to 5.00 pm depend on the rise in air temperature between inlet and outlet (ΔT) starts small in the morning and gradually increases until it reached maximum after noon then decreased gradually until sunset. The average effectiveness for collector ranged from 20% to 54%.and it was bitter at fan speed 3 m/s, compering with the others velocities.

Dryer efficiency (%ƞ): -

The daily dryer efficiency given in Fig. (8) and it were ranged from (6.97 to 63.79%),(4.12 to 43.94%) and (2.11 to 29.06%) at air speed 1.5, 2.2 and 3 m/s , respectively.

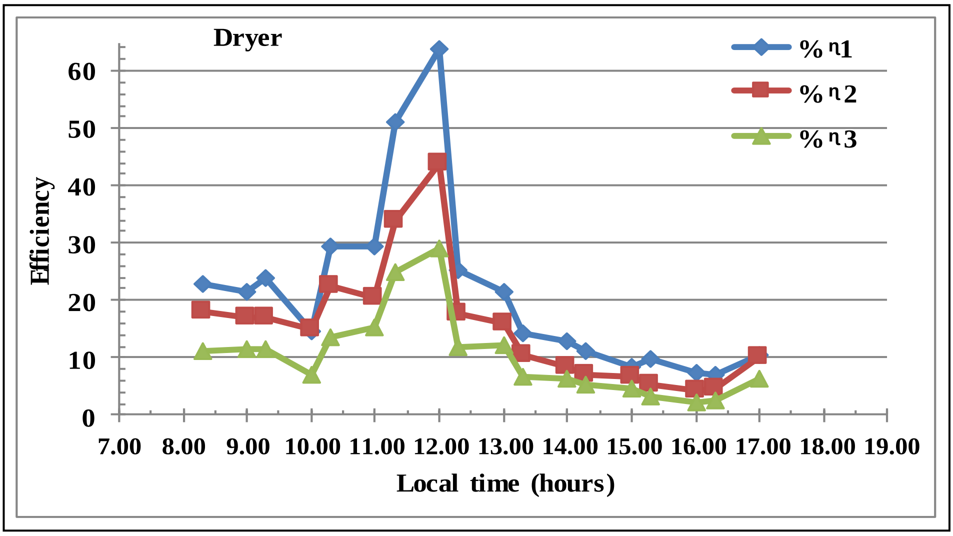

Fig. (8): Daily collector efficiency versus flow rates and local time.

It observed the system dryer efficiency at air speed 1.5 m/s, was higher comparatively to other velocities. There is a seasonal variation in the climatic parameters of ambient air and the solar radiation so that the average efficiency of is not uniform and are often ranged from 5 to 46%. The thermal efficiency is higher on the first hours of drying because the presence of moisture near to the surface of the product; then decreased continuously until the end of drying because the moisture content of the product is also decreased; so that it required more energy to drive out the same amount of moisture from the product.

Dryer effectiveness (%EI):-

Fig.(9) shed light on the effectiveness of the dryer which are ranged from 18.91% to 37.77%, 26.92% to 42.11% and 22.98% to 55.69% for air speed rates 1.5, 2.2 and 3 m/s, respectively. it observed that the effectiveness of air speed 3 m/s, is the optimum almost the time.

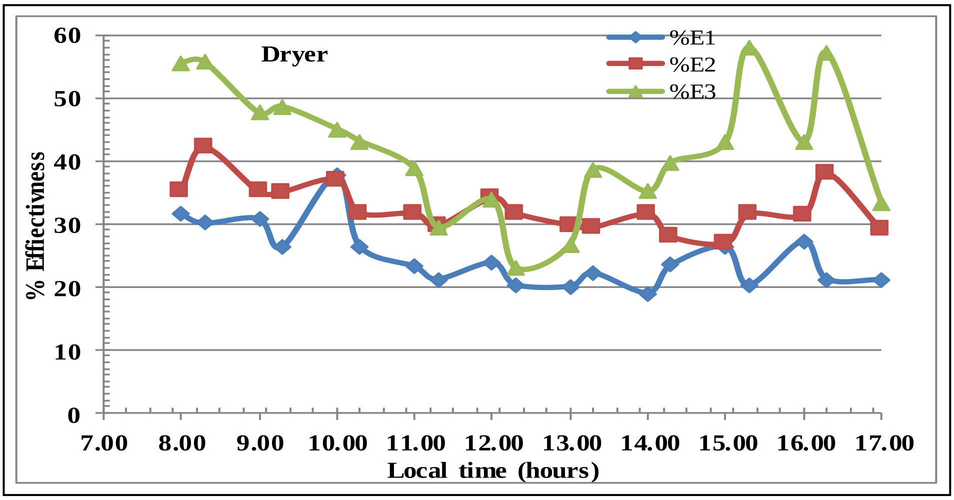

Fig. (9): Daily dryer effectiveness versus flow rates and local time.

Effect of shelf position on moisture content and draying rate:-

The variation in temperature inside the drying chamber after loading the temperature at the bottom Tray$_1$ is higher and reduces when air goes through different trays in an upward direction. Chamber temperature is minimum for the upper Tray$_3$. The products in Tray$_1$ absorb heat energy from heated air and then the heated air flows to Tray$_2$ and subsequently Tray$_3$. Therefore, the chamber temperature is reduced from Tray$_1$ to Tray$_3$. Average temperature for (Tray$_1$, Tray$_2$ and Tray$_3$) are observed as (40.95,40.62and38.68°C), (40.53,38.34and35.95°C) and (43.72,41.33and 38.11°C) for onions slices 5 mm while it were (39.84,37.89 and36.14°C), (39.65,37.77and35.58°C) and (42.67,40.40 and37.37°C) for onions slice 10 mm at air speed rates 1.5, 2.2 and 3 m/s, respectively. From Fig.10and11 it is observed that the moisture content of onions slices is varied with tray location. Drying rate is higher for the bottom tray as sample comes directly in contact with high-temperature air.

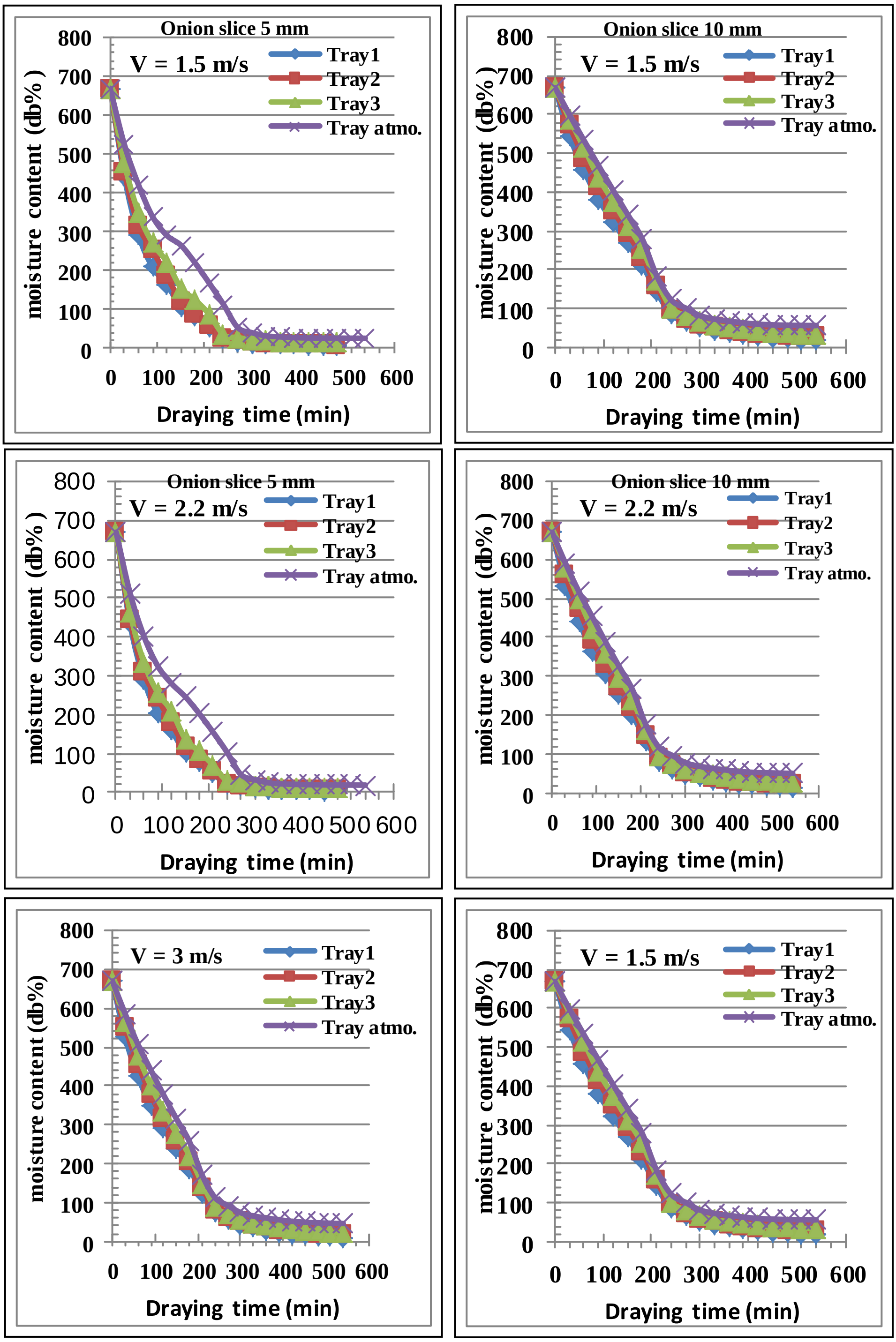

Fig. (10): Effect of self-position on onions slices 5 and 10 mm drying of various times at speed 1.5, 2.2 and 3 m/s.

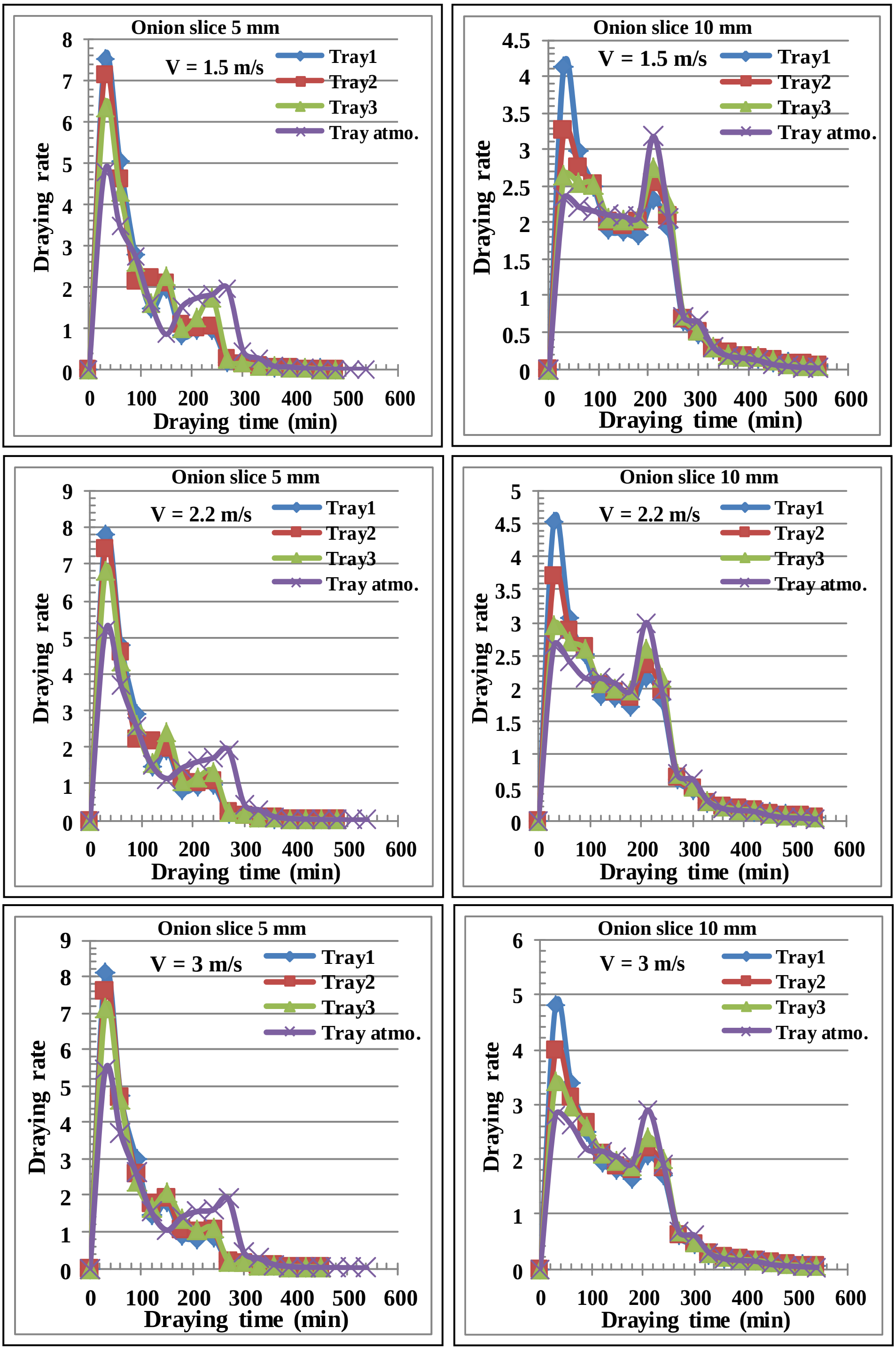

Fig. (11): Effect of drying rate for onions slices 5 and 10 mm drying of various times at speed 1.5, 2.2 and 3 m/s.

In the case of open sun drying, initially, the rate of drying is higher because of the air flow over the product from all the direction. When the temperature inside the dryer increases, and then the drying rate is higher compared to the open sun drying. The drying rate gradually reduces in the later period. There was two drying period found from the results called falling rate period. For the first falling period, drying rate is very fast due to the large difference in the moisture content of onion slices and dry air. The second d falling period, the rate of drying is slow as moisture gradient of onions slice and outside air is reduced. The moisture content of onions slices 5 mm was reduced from the average value of 696.23 % (db) to final moisture content of (6.95,8.69,14.41and25.78%), (4.27,5.26,9.89and19.04%) and (2.04,3.09, 7.52 and16.95%) for ($Tray_1$, $Tray_2$, $Tray_3$, $Tray_4$, and Tray atmospheric) while it were (19.33, 26.90, 33.51 and 56.49 %) , (14.41, 21.35 , 27.71and50.37%) and (9.89,16.27,21.95and45.98%) for 10 onions slices mm at air speed rates 1.5, 2.2 and 3 m/s, respectively.

Fitting model for describing drying process:-

The obtained statistical parameters for data fitting for the 5 mathematical models of drying onions slices at various temperatures and air speed are presented in table (3-5). All approximate models were calculated using SPSS and MS Excel. The best is the one which has a maximum R^2 and a minimum x^2.The five models revealed high values of R^2 onion slices 5 mm varied between (0.9961 and 0.9396), (0.9948 and0.9527) and (0.9961 and 0.9423) while it were (0.9839 and 0.9482), (0.9899 and 0.9558) and (0.9867 and 0.9482) for air speed rates 1.5, 2.2 and 3 m/s, respectively. Accordingly, all tested models for onions slices 5 mm Modified page and Henderson and Pabis and Modified page models displayed the highest average value of R^2 and the lowest values of X^2, RMSE and %E for fan speed while onions slices 10 mm Modified page, Page and Lewis (1.5, 2.2 and3 m/s,) respectively. Consequently, this model is the best one among the tested models that accurately express the thin layer drying behavior of onion slices under the studied conditions.

Calculation of effective moisture diffusivity (D_{eff}):-

Fig.12 illustrated the values of ln (MR) versus the drying time (t) of onions slices at the various experimental conditions.

Table (3) Statistical results obtained for thin layer drying models for onions at 1.5 m/s, and sundry.

Model	Tray no.	Thickness	Constants			Determination Statistical Coefficient				
			k	N	a	R^2	X^2	MBE	RMS	%E
Lewis	T_1	5 mm	-0.010080	-	-	0.952600	0.002822	0.039753	0.051432	-1.252679155
		10 mm	-0.007247	-	-	0.968300	0.001210	-0.005083	0.033800	0.099141376
	T_2	5 mm	-0.010031	-	-	0.942300	0.001316	0.027475	0.035121	-0.811548929
		10 mm	-0.006749	-	-	0.956200	0.002092	-0.009664	0.044451	0.175283297
	T_3	5 mm	-0.008863	-	-	0.939600	0.002091	0.034938	0.044434	-0.726045729
		10 mm	-0.006381	-	-	0.948200	0.003044	-0.014295	0.053622	0.244541445
	$T_{atmo.}$	5 mm	-0.006993	-	-	0.917500	0.001245	0.012325	0.034285	-0.248293493
		10 mm	-0.005383	-	-	0.919500	0.003394	-0.000154	0.240198	0.002402989
Page	T_1	5 mm	0.019849	0.906243	-	0.985300	0.000148	-0.000258	0.011367	0.008133786
		10 mm	0.005044	1.065370	-	0.983900	0.000842	-0.000644	0.027364	0.012568982
	T_2	5 mm	0.015686	0.940655	-	0.979900	0.000297	-0.001559	0.016119	0.046046314
		10 mm	0.003307	1.125559	-	0.980600	0.001069	0.001844	0.030819	-0.0334517
	T_3	5 mm	0.013039	0.952522	-	0.977500	0.000439	-0.003195	0.019593	0.084182742
		10 mm	0.002270	1.179732	-	0.977900	0.001353	0.004047	0.034677	-0.069225283
	T atmo.	5 mm	0.007992	0.987236	-	0.967500	0.001290	-0.003165	0.033866	0.063756123
		10 mm	0.002045	1.174424	-	0.968400	0.002236	0.006196	0.044580	-0.096859209
Modified page	T_1	5 mm	0.013232	0.906243	-	0.996100	0.000148	-0.000258	0.011367	0.008133786
		10 mm	0.006978	1.065370	-	0.983900	0.000842	-0.000644	0.027364	0.012568982
	T_2	5 mm	0.012069	0.940655	-	0.979900	0.000297	-0.001559	0.016119	0.046046314
		10 mm	0.006254	1.125559	-	0.980600	0.001069	0.001844	0.030819	-0.0334517
	T_3	5 mm	0.010503	0.952522	-	0.977500	0.000439	-0.003195	0.019593	0.084182742
		10 mm	0.005739	1.179732	-	0.977900	0.001353	0.004047	0.034677	-0.069225283
	T atmo.	5 mm	0.007508	0.987236	-	0.967500	0.001290	-0.003165	0.033866	0.063756123
		10 mm	0.005130	1.174424	-	0.968400	0.002236	0.006196	0.044580	-0.096859209
Modified page II	T_1	5 mm	0.366961	0.906243	-	0.985300	0.000148	-0.000261	0.011368	0.008216381
		10 mm	0.681608	1.065370	-	0.983900	0.000842	-0.000642	0.027364	0.012524487
	T_2	5 mm	0.323971	0.940655	-	0.979900	0.000297	-0.001568	0.016122	0.046302383
		10 mm	0.589606	1.125559	-	0.980600	0.001069	0.001865	0.030820	-0.033825413
	T_3	5 mm	0.279766	0.952522	-	0.977500	0.000439	-0.003185	0.019590	0.083911128
		10 mm	0.519442	1.179732	-	0.977900	0.001353	0.004039	0.034675	-0.069091909
	T atmo.	5 mm	0.191762	0.987236	-	0.967500	0.002585	-0.009732	0.047938	0.196048986
		10 mm	0.456576	1.174424	-	0.968400	0.002236	0.006201	0.044582	-0.09694058
Henderson and Pabis	T_1	5 mm	0.010000	-	0.7211	0.952600	0.007074	-0.025513	0.078677	0.803961986
		10 mm	0.007000	-	0.9633	0.968300	0.001675	-0.007512	0.038589	0.146515498
	T_2	5 mm	0.0.01	-	0.762600	0.942300	0.002335	-0.015869	0.045560	0.85126376
		10 mm	0.007000	-	0.970400	0.965600	0.003499	-0.026945	0.055773	0.488726319
	T_3	5 mm	0.009000	-	0.800600	0.976400	0.004565	-0.027909	0.063204	0.73527397
		10 mm	0.006000	-	0.984100	0.948200	0.003267	-0.003734	0.053887	0.06387404
	T atmo.	5 mm	0.007000	-	0.878100	0.917500	0.005727	-0.021216	0.071351	0.463322581
		10 mm	0.005000	-	0.938300	0.938300	0.005357	-0.002789	0.069004	0.043607619

Table (4) Statistical results obtained for thin layer drying models for onions at 2.2 m/s, and sundry.

Model	Tray no.	Thickness	Constants			Determination Statistical Coefficient				
			k	n	a	R^2	X^2	MBE	RMS	%E
Lewis	T_1	5 mm	-0.012006	-	-	0.976300	0.000547	0.014409	0.022597	-0.467840717
		10 mm	-0.007728	-	-	0.978500	0.001031	-0.007715	0.031210	0.157065718
	T_2	5 mm	-0.011121	-	-	0.962800	0.000529	0.014436	0.022259	-0.439843605
		10 mm	-0.007118	-	-	0.965600	0.001491	-0.007827	0.037521	0.149030271
	T_3	5 mm	-0.009645	-	-	0.952700	0.001021	0.245980	0.030940	-0.649625845
		10 mm	-0.006706	-	-	0.955800	0.002492	-0.013317	0.048516	0.237507917
	T atmo.	5 mm	-0.007655	-	-	0.923500	0.001044	0.006257	0.031403	-0.133154158
		10 mm	-0.005560	-	-	0.927300	0.002700	0.003820	0.214248	-0.061947173
Page	T_1	5 mm	0.014426	0.991040	-	0.994000	0.000214	-0.002698	0.013533	0.090641567
		10 mm	0.006211	1.048543	-	0.989900	0.000591	-0.002581	0.022914	0.055010459
	T_2	5 mm	0.012942	0.999005	-	0.990200	0.000326	-0.003433	0.016802	0.108451164
		10 mm	0.004684	1.083964	-	0.987400	0.000622	-0.000066	0.023505	0.001321519
	T_3	5 mm	0.014104	0.960781	-	0.988600	0.000321	-0.002234	0.016668	0.06548521
		10 mm	0.003596	1.118587	-	0.984200	0.000810	0.001535	0.026828	-0.028814217
	T atmo.	5 mm	0.009041	0.983155	-	0.968500	0.001187	-0.004914	0.032478	0.10704976
		10 mm	0.003039	1.118050	-	0.973700	0.001565	0.004545	0.037295	-0.075666817
Modified page	T_1	5 mm	0.013884	0.991040	-	0.994000	0.000214	-0.002698	0.013533	0.090641567
		10 mm	0.007859	1.048543	-	0.989900	0.000591	-0.002581	0.022914	0.055010459
	T_2	5 mm	0.012886	0.999005	-	0.990200	0.000326	-0.003433	0.016802	0.108451164
		10 mm	0.007096	1.083964	-	0.987400	0.000622	-0.000066	0.023505	0.001321519
	T_3	5 mm	0.011852	0.960781	-	0.988600	0.000321	-0.002234	0.016668	0.06548521
		10 mm	0.006530	1.118587	-	0.984200	0.000810	0.001535	0.026828	-0.028814217
	T atmo.	5 mm	0.008341	0.983155	-	0.968500	0.001187	-0.004914	0.032478	0.10704976
		10 mm	0.005604	1.118050	-	0.973700	0.001565	0.004545	0.037295	-0.075666817
Modified page II	T_1	5 mm	0.350393	0.991040	-	0.994000	0.000214	-0.002692	0.013530	0.090437182
		10 mm	0.776701	1.048543	-	0.989900	0.000591	-0.002577	0.022913	0.054924062
	T_2	5 mm	0.322517	0.999005	-	0.990200	0.000326	-0.003437	0.016804	0.10859911
		10 mm	0.689423	1.083964	-	0.987400	0.000621	-0.000057	0.023504	0.001143361
	T_3	5 mm	0.310802	0.960781	-	0.988600	0.000321	-0.002246	0.016672	0.065837979
		10 mm	0.620829	1.118587	-	0.984200	0.000810	0.001531	0.026827	-0.028743698
	T atmo.	5 mm	0.214103	0.983155	-	0.968500	0.001187	-0.004924	0.032482	0.10726498
		10 mm	0.523353	1.118050	-	0.973700	0.001565	0.004548	0.037296	-0.075701498
Henderson and Pabis	T_1	5 mm	0.014000	-	1.0499	0.994800	0.001687	-0.004424	0.038727	-0.1891057
		10 mm	0.008000	-	1.0133	0.986700	0.000698	0.000457	0.024912	-0.009734806
	T_2	5 mm	0.013000	-	0.994700	0.984800	0.000368	-0.006068	0.017868	0.191714139
		10 mm	0.0.008	-	0.981800	0.974600	0.002402	-0.026141	0.046208	0.520352645
	T_3	5 mm	0.011000	-	0.882900	0.974200	0.001714	-0.019082	0.038537	0.559367514
		10 mm	0.007000	-	0.979600	0.965000	0.002221	-0.013882	0.044436	0.260656036
	T atmo.	5 mm	0.008000	-	0.895800	0.927900	0.002631	-0.024234	0.048357	0.527909464
		10 mm	0.006000	-	0.921300	0.932800	0.005105	-0.033186	0.067362	0.552435647

Table (5) Statistical results obtained for thin layer drying models for onions at 3m/s, and sundry.

Model	Tray no.	Thickness	Constants			Determination Statistical Coefficient				
			k	n	a	R^2	X^2	MBE	RMS	%E
Lewis	T_1	5 mm	-0.014050	-	-	0.994800	0.000253	-0.005332	0.015330	0.179106093
		10 mm	-0.008316	-	-	0.986700	0.000980	-0.011200	0.030427	0.238748461
	T_2	5 mm	-0.012921	-	-	0.984800	0.000314	-0.003956	0.017106	0.124999001
		10 mm	-0.007560	-	-	0.974600	0.001211	-0.008998	0.033817	0.179117453
	T_3	5 mm	-0.010777	-	-	0.974200	0.000495	0.012539	0.021493	-0.36755286
		10 mm	-0.007077	-	-	0.965000	0.002543	-0.025137	0.049012	0.471984025
	T atmo.	5 mm	-0.007869	-	-	0.927900	0.006181	0.130220	0.030693	-0.134640545
		10 mm	-0.005708	-	-	0.932800	0.002307	0.005648	0.198043	-0.094015526
Page	T_1	5 mm	0.019849	0.906243	-	0.985300	0.000148	-0.000258	0.011367	0.008133786
		10 mm	0.005044	1.065370	-	0.983900	0.000842	-0.000644	0.027364	0.012568982
	T_2	5 mm	0.015686	0.940655	-	0.979900	0.000297	-0.001559	0.016119	0.046046314
		10 mm	0.003307	1.125559	-	0.980600	0.001069	0.001844	0.030819	-0.0334517
	T_3	5 mm	0.013039	0.952522	-	0.977500	0.000439	-0.003195	0.019593	0.084182742
		10 mm	0.002270	1.179732	-	0.977900	0.001353	0.004047	0.034677	-0.069225283
	T atmo.	5 mm	0.007992	0.987236	-	0.967500	0.001290	-0.003165	0.033866	0.063756123
		10 mm	0.002045	1.174424	-	0.968400	0.002236	0.006196	0.044580	-0.096859209
Modified page	T_1	5 mm	0.013232	0.906243	-	0.996100	0.000148	-0.000258	0.011367	0.008133786
		10 mm	0.006978	1.065370	-	0.983900	0.000842	-0.000644	0.027364	0.012568982
	T_2	5 mm	0.012069	0.940655	-	0.979900	0.000297	-0.001559	0.016119	0.046046314
		10 mm	0.006254	1.125559	-	0.980600	0.001069	0.001844	0.030819	-0.0334517
	T_3	5 mm	0.010503	0.952522	-	0.977500	0.000439	-0.003195	0.019593	0.084182742
		10 mm	0.005739	1.179732	-	0.977900	0.001353	0.004047	0.034677	-0.069225283
	T atmo.	5 mm	0.007508	0.987236	-	0.967500	0.001290	-0.003165	0.033866	0.063756123
		10 mm	0.005130	1.174424	-	0.968400	0.002236	0.006196	0.044580	-0.096859209
Modified page II	T_1	5 mm	0.366961	0.906243	-	0.985300	0.000148	-0.000261	0.011368	0.008216381
		10 mm	0.681608	1.065370	-	0.983900	0.000842	-0.000642	0.027364	0.012524487
	T_2	5 mm	0.323971	0.940655	-	0.979900	0.000297	-0.001568	0.016122	0.046302383
		10 mm	0.589606	1.125559	-	0.980600	0.001069	0.001865	0.030820	-0.033825413
	T_3	5 mm	0.279766	0.952522	-	0.977500	0.000439	-0.003185	0.019590	0.083911128
		10 mm	0.519442	1.179732	-	0.977900	0.001353	0.004039	0.034675	-0.069091909
	T atmo.	5 mm	0.191762	0.987236	-	0.967500	0.002585	-0.009732	0.047938	0.196048986
		10 mm	0.456576	1.174424	-	0.968400	0.002236	0.006201	0.044582	-0.09694058
Henderson and Pabis	T_1	5 mm	0.010000	-	0.7211	0.952600	0.007074	-0.025513	0.078677	0.803961986
		10 mm	0.007000	-	0.9633	0.968300	0.001675	-0.007512	0.038589	0.146515498
	T_2	5 mm	0.0.01	-	0.762600	0.942300	0.002335	-0.015869	0.045560	0.85126376
		10 mm	0.007000	-	0.970400	0.965600	0.003499	-0.026945	0.055773	0.488726319
	T_3	5 mm	0.009000	-	0.800600	0.976400	0.004565	-0.027909	0.063204	0.73527397
		10 mm	0.006000	-	0.984100	0.948200	0.003267	-0.003734	0.053887	0.06387404
	T atmo.	5 mm	0.007000	-	0.878100	0.917500	0.005727	-0.021216	0.071351	0.463322581
		10 mm	0.005000	-	0.938300	0.938300	0.005357	-0.002789	0.069004	0.043607619

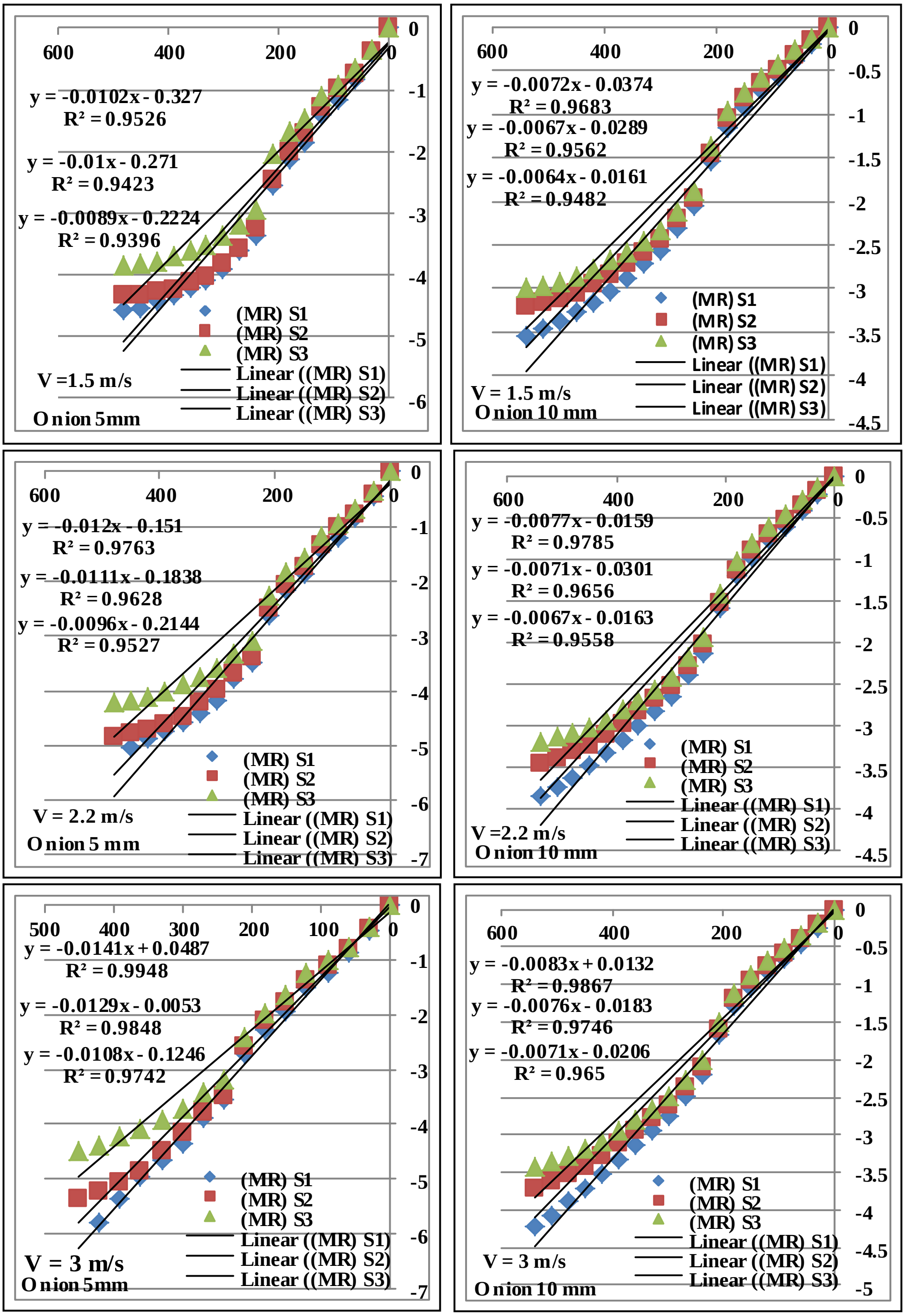

Fig. (12). Experimental logarithmic moisture ratio (MR) in function drying time for drying onions slices 5 and 10 mm.

The deviation from linearity of the experimental logarithmic drying curve indicates effective moisture diffusion coefficient (D_{eff}) is dependent on the moisture content (**Celma et al., 2008**). Thus, using non-linear regression a second order polynomial equation relating ln (MR) and the drying time (t) was established with a good fitting of the experimental results. The dependency of the effective moisture diffusivity on moisture content may be due to the varied kinetics that causes moisture moving during the drying process. In the starting of the drying process, when the samples have a great amount of moisture, the moisture movement is mainly by liquid diffusion.

Table (6):-Moisture diffusivity for onions slices at various air flow rate.

Air speed	Tray No.	Thickness	Average Temp.	Diffusivity coefficient (D_{eff}) m^2/s
1.5 m/s	T_1	5 mm	40.95	1.72958×10^{-9}
		10mm	39.83	4.89539×10^{-9}
	T_2	5 mm	40.61	1.69385×10^{-9}
		10mm	37.89	4.55877×10^{-9}
	T_3	5 mm	38.68	1.496623×10^{-9}
		10mm	36.14	4.31037×10^{-9}
2.2 m/s	T_1	5 mm	40.53	2.02947×10^{-9}
		10mm	39.65	5.22036×10^{-9}
	T_2	5 mm	38.33	1.87794×10^{-9}
		10mm	37.77	4.80804×10^{-9}
	T_3	5 mm	35.95	1.62875×10^{-9}
		10mm	35.58	4.52978×10^{-9}
3 m/s	T_1	5 mm	43.72	2.37261×10^{-9}
		10mm	42.67	5.61732×10^{-9}
	T_2	5 mm	41.33	2.18188×10^{-9}
		10mm	40.40	5.10661×10^{-9}
	T_3	5 mm	38.11	1.81985×10^{-9}
		10mm	37.37	4.78007×10^{-9}

Table 6 clear the values of D at different levels of air temperature and versus air velocity. As seen, the minimum value of D was found at the minimum air temperature while it D value increase with increase of air velocity the air has a better contact with the sample surface which results in a greater absorption of moisture, consequently the moisture gradient of the sample with ambient increases and that leads to an increase in the moisture diffusivity.

Computation of activation energy (Ea):-

The activation energy (Ea) is a measure of the effect on the diffusion coefficient. Activation energy (Ea) calculated from the linear regression Table (7). The values of the activation energy lie from 12.7 to 110 kJ/mol for most food materials (Zogzas 1996). Ea value varied from 23.49 to 29.82 kJ/ mol for onions slices 5 mm and from 16.09 to 18.01 kJ/ mol for different air velocities. The relationship between the activation energy and drying air velocity was found by regression analysis. The results indicated that the power equation can predict Ea based on the drying air velocity.

Table (7) Diffusivity coefficient and activation energy at various air rates.

Air speed	Thickness	D_O	Ea (kJ/mol K)
1.5 m/s	5 mm	4.15×10^{-9}	23.49
	10mm	1.14×10^{-8}	16.09
2.2 m/s	5 mm	4.63×10^{-9}	25.94
	10mm	1.22×10^{-8}	17.04
3 m/s	5 mm	5.29×10^{-9}	29.82
	10mm	1.28×10^{-8}	18.01

Payback analysis:-

The payback period is calculated as the time required for the investment cost to equal the return. In our case the payback period is very small (1.05 year) compared to the life of the dryer (25 years), so the dryer will dry product free of cost for almost its entire life period.

$$\text{Payback period} = \frac{12000}{11400} = 1.05 \text{ year.}$$

Rehydration Characteristics:-

The rehydration ratio of dried onions slices is presented in table 8. The rehydration ratio and coefficient of rehydration were calculated to return to the base block of the dried apricots. Higher rehydration ratio indicates better product. The rehydration ratio ranged from 2.95 to 2.48 for onion slices 5 mm while it were ranged from 2.69 to 2.10 for onion slices 10 mm for different air flow. The three varieties of the dried onions slices were having greater rehydration ratio at air speed 3 m/s, and high temperature compared with others sample dried. At lower air speed and high Temperature plant cells are less vandalized, so that the material is capable of more absorption of water (**Apar et al 2009**). It was noted that as the air speed decreased there is no great difference in the rehydration ratio and coefficient of rehydration with different parameters.

Table 8:- Rehydration Characteristics of onions slices at various air speed rates.

Air speed	Tray No.	Thickness	Av. Temp	RR	COR
1.5 m/s	T_1	5 mm	40.95	2.69	0.374010695
		10mm	39.83	2.40	0.372315036
	T_2	5 mm	40.61	2.62	0.370217391
		10mm	37.89	2.22	0.366243655
	T_3	5 mm	38.68	2.48	0.368878719
		10mm	36.14	2.10	0.364485981
Sun dry	T atmo.	5 mm	33.66	1.95	0.301785714
		10mm	33.66	1.50	0.293233083
2.2 m/s	T_1	5 mm	40.53	2.80	0.379562044
		10mm	39.65	2.50	0.371853547
	T_2	5 mm	38.33	2.72	0.372210526
		10mm	37.77	2.35	0.370752427
	T_3	5 mm	35.95	2.58	0.368571429
		10mm	35.58	2.20	0.365261814
Sun dry	T atmo.	5 mm	32.72	2.04	0.315714286
		10mm	32.72	1.80	0.351879699
3 m/s	T_1	5 mm	43.72	2.95	0.391326531
		10mm	42.67	2.69	0.384285714
	T_2	5 mm	41.33	2.85	0.381958763
		10mm	40.40	2.51	0.379418605
	T_3	5 mm	38.11	2.70	0.377419355
		10mm	37.37	2.36	0.374146341
Sun dry	T atmo.	5 mm	33.09	1.97	0.299532164
		10mm	33.09	1.55	0.294160584

CONCLUSION

1- The average daily collector efficieny arrived to 44.92,65.28 and 89.19% for air speed 1.5,2.2 and 3 m/s, respectively.

2- The average effectiveness for collector ranged from 20% to 54%collector while the dryer ranged from 5 to 46% respectively.

3- Modified page, Henderson and Modified page was selected as a suitable model to drying onions slices 5 mm wihle Page, Henderson and Lewis for onions slices 10 mm highest value of R^2 and the lowest value of x^2 for air speed 1.5, 2.2 and3 m/s, respectively.

4- The rehydration ratio of dried onions slices 5 mm ranged from 2.48 to 2.95% while it was ranged from 2.10 to 2.69 % respectively.

5- The Effective moisture diffusivity varied from 1.72958× 10^{-9} to 2.37261× 10^{-9} m^2/s for onions slices 5mm while it were varied from 4.31037× 10^{-9} to 5.61732× 10-9 m^2/s .
6- The activation energy varied from 23.49 to 29.82kJ/mol k for onions slices 5mm while it were varied from 16.09 to 18.01 kJ/mol k for onions slices 10 mm respectively.
7- the payback period for is solar dryer were1.05 year.

Nomenclature

a, n	empirical coefficients in drying models
MR	moisture ratio (dimensionless)
k_L, k_P, k_M, k_H	Empirical constants in drying models (s^{-1})
t	Drying time (min)
L	thickness of the sample (slab) (m)
MR_{Exp}	experimental moisture ratio (dimensionless)
MR_{Prd}	predicted moisture ratio (dimensionless)
MR_{Prd}	the average predicted moisture ratio
n	number of constants
N	Number of observations
D_{eff}	Effective moisture diffusivity (m^2/s)
Mt	Moisture content at time t, %wb (wet base) or db (dry base)
Mo	Initial moisture content, %wb
Me	Equilibrium Moisture
D_o	Pre-exponential factor of Arrhenius equation (m^2/s).
Ea	Activation energy
R	Universal gas constant (8.3143 kJ/(kmol. K))
Tabs	absolute air temperature (K)
Qconv	converted heat (W/m2)
Cp	specific heat of air 1007 (J/kg.^{o}c)
m	mass flow rate of air (kg/s)
Tin_{-coll}	air temperature inlet solar collector (^{o}c)
Tout-coll	air temperature at outlet of solar collector (^{o}c)
Ac	absorbent area (m2)
Tin_{-chamb}	air temperature inlet chamber (^{o}c)
$Tout_{-chamb}$	air temperature at outlet of chamber(^{o}c)
Rad	solar radiation (W/m2)
ma	Weight of air (kg)
me	mass of moisture evaporated in time t
Le	latent-heat of vaporization of moisture (kJ/kg)
T_{amb}	ambient air temperature (^{o}c)
v	air flow velocity, m/s,
R_r	Rehydration ratio
w_r	weight of rehydrated sample, g.
W_d	weight of dry sample, g.
M_i	Moisture content of samples before dehydration, % (wb)
M_f	Moisture content of dehydrated samples, % (wb)

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الملخص العربى

تصميم نموذج لمجفف شمسي- كهربائى غيرمباشر لتجفيف شرائح البصل الأبيض

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أجريت هذه التجربة بمدينة الزقازيق بمحافظة الشرقية عند خط عرض ٣٠ ⁻ °٣٤ وطول ٣١⁻ °٣٠ فى شهرسبتمبر٢٠١٨ باستخدم نموذج جديد لمجفف كهربائى شمسى الصنع لتجفيف شرائح البصل الابيض سمك ٥و١٠مللى واشتملت تلك الوحدة على مجمع شمسى عبارة عن صندوق معدنى مزدوج الجدران بابعاد ٢,٥×١×٠,١٥ (طول × عرض × الارتفاع) من الصاج المجلفن بسمك ٠,٠٠٢ م ومعزول بالفيبر الزجاجى بسمك ٠,٠٢٥ م من الجوانب و٠,٠٥ م من اسفل المجمع مع استخدام صفيحة امتصاص معدنية متعرجة من الصاج المجلفن لها زاوية تضليع ° 55 وبارتفاع ٠,٠٥ م من المنتصف مدهونة بطلاء اسود غير لامع حيث تم وضع غطاء من الزجاج على المجمع بسمك ٥ مللى لمنع الفقد الحرارى من المجمع وكان وسط التسخين هو الهواء مع ترك فجوة هوائية بين صفيحة الامتصاص والغطاء الزجاجى مقدرها ٠,٢ م والمجفف عبارة عن صندوق معدنى مزدوج الجدران من الصاج المجلفن تجفيفه بابعاد ١,٥×١×٠,٥٠ م (طول × عرض × العمق) ومعزول من الجوانب و من اسفل واعلى المجفف مثل المجمع وبداخله رفوف مثقبة يوضع عليها شرائح البصل المراد وهو عبارة عن سمك ٥ و ١٠ مللى وكذلك باب مزدوج لوضع المنتج حيث يتم سحب الهواء من المجمع الى المجفف بواسطة مروحتين كهربائيتيين قدرة ١٦ وات بثلاثة سرعات مختلفة وهى ١,٥ ، ٢,٢، ٣ م / ث عبر اربعة مواسير من البلاستيك وقد تم إجراء هذا البحث لحساب افضل موديل تجفيف وافضل سرعة هواء لاجراء عملية التجفيف و كفاءة وفاعلية كلا من المجمع الشمسى و المجفف و فاعلية الانتشار الرطوبى و طاقة التفعيل.

و قد تبين من النتائج المتحصل عليها كل مما يأتي :

-كانت متوسط كفاءة المجمع الشمسى اليومية ٤٤,٩٢ ٪ ، ٦٥,٢٨ ٪ و ٨٩,١٩ ٪ لسرعة الهواء ١,٥ و٢,٢ ٣ م/ ث على الترتيب.

- تراوح متوسط الفعالية اليومية للمجمع الشمسى من ٢٠ إلى ٥٤٪ بينما تراوحت للمجفف بين ٥ إلى ٤٦٪ على التوالي.

-كانت معادلة Modified Page افضل نموذج لمحاكاة تجفيف شرائح البصل ٥ و ١٠ مللى $(R^2=0.9961 and 0.9899)$ $(X^2 =0.000148 and 0.000591)$ وذلك عند سرعة ٣ م/ث.

- تراوحت فعالية انتشار الرطوبة من ١,٧٢٩٥٨×١٠⁻⁹ الى ٢,٣٧٢٦١×١٠⁻⁹ بينما كانت من٤,٣١٠٣٧×١٠⁻⁹ إلى ٥,٦١٧٣٢×١٠⁻⁹ م ٢ / ثانية لشرائح البصل ٥ و١٠مم على الترتيب.

- تتراوح طاقة التنشيط من ٢٣,٤٩ إلى ٢٩,٨٢ كيلو جول / مول . كلفن بينما كانت تتراوح من ١٦,٠٩ إلى ١٨,٠١ كيلو جول / مول . كلفن لشرائح البصل ٥ و١٠مم على الترتيب.

- فترة الاسترداد للمجفف كانت ١,٠٥ سنة.

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