DESIGN AND EVALUATION DIRECT SOLAR-DRYER TO DRY RED ONIONS SLICES

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ABSTRACT

An direct solar–electrical dryer has been designed and constructed at a Zagazig City of , Sharkia governorate, Egypt. Solar dryer consists of solar flat plate air collector with V-corrugated absorption plate in conecation with drying tray uint. The red onions most popular to consumer no dayes in the Zagazig City so that it was chosen to experiment. The new dryer prototype was tested its efficiency for drying red onions slices 5 &10 mm to study the effect of drying air velocities (0.4,0.5 and 0.6 m/s) at air temperature (40.82,42.37 and 43.81)respectiviely.The qualitative analysis for drying of onions slices 5 mm showed that initial moisture content of about 88% (wet basis) was reduced to final moisture content of about (10%,12% and 16%) for velocities (0.4,0.5 and 0.6 m/s),while it were (16%,18% and 20.8%) for onions slices 10 mm respectiviely.The average percent of dryer efficiency was found to be 16.07, 12.83 and 12 % for air speed 0.4,0.5 and 0.6 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 page and Modified page II model in this condition proved to be the best for predicting drying behavior of red onions slices 5 and 10 mm with (R^2 = 0.9961 and 0.9899) and (X^2 = 0.000121 and 0.000423).The effective moisture diffusivity (Deff) was obtained using Fick's diffusion equation and its value varied from 1.46×10^{-9} to 1.59×10^{-9} m^2/s and 5.25×10^{-9} to 5.72×10^{-9} m^2/s. The temperature dependence of the diffusivity coefficients was described with the activation energy (Ea) value of 21.33 kJ/mol and 19.14 kJ/mol for red onions slices 5 and 10mm.Finally an economic evaluation was calculated using the criterion of payback period which is found very small 1.84 years compared to the life of the dryer 25 years.

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

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INTRODUCTION

During the last few years, drying onion, is one of the raw materials claiming great interest and demand, both in international and national markets as considered one of the most important as a vegetable crops. storing onions led to tendency to drying it using solar dryers as alternative sources to conserve the environment.

Lyes and Azeddine (2003) designed solar dryer for onion.The results showed that drying is affected by the surface of the collector, the air temperature and the product characteristics. Significant improvements were registered in the results, after the heater is added.

Drying is useful to preserve food quality and stability, lowering the water activity through the decrease of moisture content, and so avoiding spoilage and contamination during the storage period (Akpinar et al. 2006).

Pankaj and Sharma (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 0.2514×10^{-10} and 0.3233×10^{-10} m^2/s while the activation energy ranged between5.06 and 10.63 kJ /mol that indicated to decrease in energy of activation.

Sarsavadia (2006) Developed A solar-assisted forced convection dryer for drying of onion slices from initial moisture content of about 86% (wet basis) to final moisture content of about 7% (wet basis), the energy required per unit mass of water removed during without using recirculation of air was found between 23.548 and 62.117 MJ/kg water.

Mota et al.(2010) studied drying onions in terms of drying kinetics, which was evaluated at 30 ◦C, 50 ◦C and 60 ◦C. The experimental data was tested with three empirical models (Newton, Modified Page and Logarithmic)all describe relatively well the dehydration kinetics at the three temperatures analysed. Moreover, from the experimental data it was possible to estimate 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 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.

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) studied drying garlic slices in thin-layer with Infrared at 0.075, 0.15, 0.225 and 0.3 W/cm2 radiation intensity and 0.75 and 1.25 m/s air flow velocity. The results showed increasing in drying rate and decreasing at the time of drying with decreasing air flow velocity and radiation intensity. The effective moisture diffusivity mean values ranged between 5.83×1011 and 7.66×1010 m^2/ s for all investigated conditions.

MATERIALS AND METHODS

The drying process was conducted by using the direct solar dryer 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). Onion slices drying by direct forced convection solar–electrical constructed and installed at at a the roof of house in Zagazig City of , Sharkia governorate, Egypt. Experiments started at 8:00 am and terminated at 5:00 pm. It was installed in an environment with the relative air humidity of 30~65%, ambient air speed of 0.8 ~ 2.8 m/s and ambient air temperature varying from 26 to 37°C under solar radiation changing between 100 and 782.4 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. dryer were installed on a raised far from the shade of buildings during the whole duration of the system trial. A schematic diagram of direct solar dryer used in the experiments is shown in Fig. (1). It was made from aluminum frame like box, sides and bottom were insulated by a layer of fiber glasses sandwiched between two parallel galvanized metal sheets with a thickness 0.025 m from the sides and 0.05 m from the bottom with walls of dimension (1 × 0.50 × 0.30) m (height, width and depth) The solar air dryer has an area of 0.5 m^2 is inclined at an angle of 19° 30' 00" N (latitude of Zagazig city) with the horizontal facing south all the time. Solar air dryer consists of three main parts it where:-

1- Corrugated plate solar collector:-

Made from galvanized sheet thickness 0.001 m and 55^{o} goffer angle and height of 0.05 m from the basises of plate and painted matte black not shiny to absorb most of the incident solar radiation with an area of 0.35 m^2.

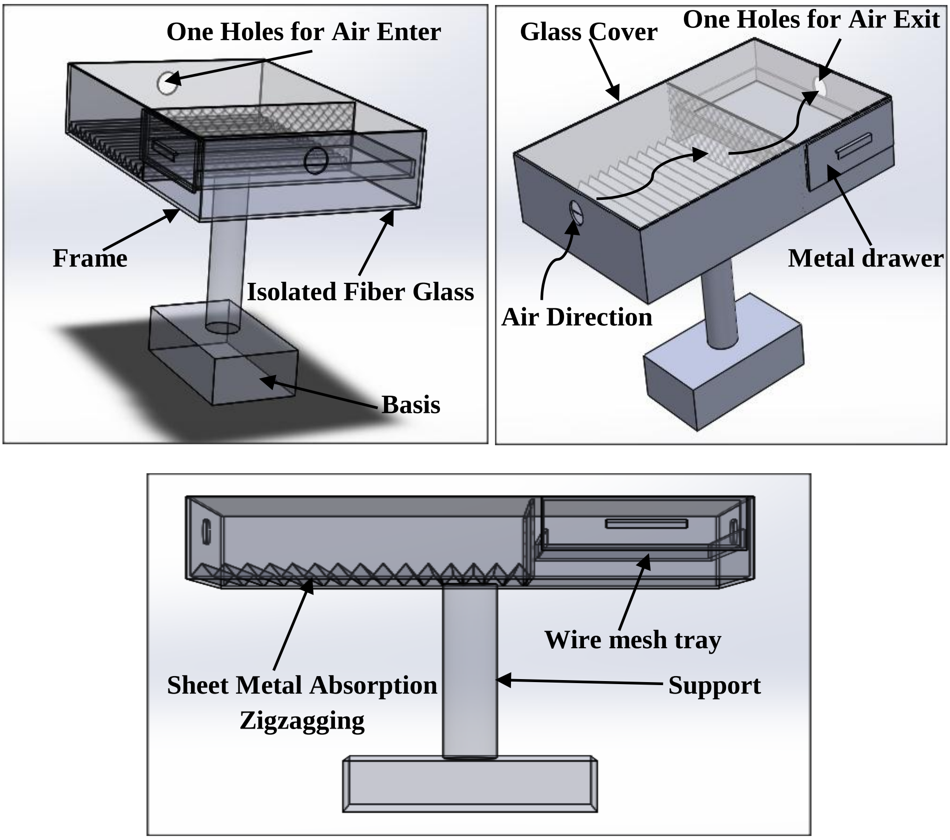

Fig. (1): A Schematic view of direct solar dryer components.

2- **Metal drawer**:- the drawer dimension of (0.30 × 0.50 × 0.30) m (height, width and depth) the bottom of the drawer was removed and replaced with a wire mesh tray, to putting the product on it.

There is a distance of 0.20 m as air gap between the glasses cover and absorbing plate. The top losses are minimized by placing a glass cover of 0.005 m thickness over the top of the dryer.

3-**Exhusted fan** :- model SA6030 power in put 5 Watt, AC 220 to 240V, running at 2500 to 3100 rpm/minute controlled manually by electrical resistance to change air velocity.

4- Sample preparation:-

Locally available red onion was used in the present study procured 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:-

Red onion slices dryed by forced solar drying, in direct solar dryer, about 100 g of onions slices were uniformly distributed load tray and kept inside the dryer while 100 g of onions slices spread in the ground and left to natural drying by open sun-light.The initial moisture content of the onions slices were 88% (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). Ambient air enters the prototype from front opening under the suction electrical fan so that the air was drawn and hated between the glass and the absorber. The hot air pass through wire mesh tray which loaded by product then get out to surrounding. Three air velocity were studied (0.4, 0.5 and 0.6 m/s). 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.

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

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

MR	Moisture ratio
Mt	Moisture content at time t, %wb (wet base) or db (dry base)
Mo	Initial moisture content, %wb
Me	Equilibrium Moisture, assume Me =0

Thin-layer drying models:- Table (1) showed the drying models tested with experimental drying data to find the most suitable for drying red onion slices.

Table (1) Mathematical models 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	$MR = \exp(-k\ (t/L^2)^n)$	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 above mentioned parameters:

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

MR_{Prd} predicted moisture ratio

MR_{Exp} experimental moisture ratio

$\overline{MR_{Prd}}$ average predicted moisture ratio

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{Exp} - MR_{Prd})^2}{N - n} \longrightarrow (3)$$

N Number of observations

N Number of observations

$$RMSE = \left[\frac{\sum_{i=1}^{N} (MR_{Prd} - \sum MR_{Exp})^2}{N}\right]^{½} \longrightarrow (4)$$

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

Moisture diffusivity and activation energy:-

Eq.(6) calculated the effective moisture diffusivity coefficient by using Fick’s second law from a slope of a straight line by plotting experimental drying data in terms of ln(MR) versus drying time(Crank, 1975).

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

D_{eff}	Effective diffusivity, m^2/s
L	Thickness of the samples (m)
T	Drying time (min)

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

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

Ea	Activation energy
D_o	Pre-exponential factor of Arrhenius equation (m^2/s).
R	Universal gas constant (8.3143) kJ/(kmol. K)
Tabs	Absolute air temperature (K)

Solar collector & 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).

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

M	mass flow rate of air (kg/s)
Cp	specific heat of air 1007 (J/kg.°c)
Rad	solar radiation (W/m^2)
Ac	absorbent area (m^2)
ΔT	difference output and input air temperatures (°c)

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

$$\%\eta_d = \frac{me * Le}{Rad\ At + E_F} \times 100 \longrightarrow (9)$$

me mass of moisture evaporated in time t

Le	latent-heat of vaporization of moisture (kJ/kg)
A	area (m^2)
EF	energy of the fan (J)

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–electrical dryer.

Cost of Cost of dryer	**3000 L.E**
Capacity of dryer	**0.5 kg**
Depreciation	**300 L.E**
Life of dryer	**25 years**
Cost of maintenance	**200 L.E**
Labor cost 5 × 360 year	**900 L.E**
Cost of electrical consumption, L.E /year	**32 L.E**
Cost of raw onions 3 × 0.5 × 360	**540 L.E**
Total cost	**1972 L.E**
Total income 360 × 0.1 × 100	**3600 L.E**
Net income	**1628 L.E**
Note 1US Dollar ≈ 18 L.E.	

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

$$\text{Payback period} = \frac{\text{Initial Investment}}{\text{Annual Net Undiscounted Benefits}} \longrightarrow (10)$$

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

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).

$$Rr = \frac{W_r}{W_d} \longrightarrow (11)$$

R_r	Rehydration ratio
Wr	weight of rehydrated sample, g.
Wd	weight of dry sample, g.

$$COR = \frac{W_r\,(100-M_i)}{W_d\,(100-M_f)} \longrightarrow (12)$$

COR	Coefficient of rehydration.
Mi	Moisture content of samples before dehydration, % (wb)

Measuring Instrumentations.

Weather station model PC-200:- Was used for monitoring solar radiation (1 ~2000 W/m^2) with 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 & 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 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.

RESULTS AND DISCUSSION

Practical trial for solar–electrical dryer under load.

Designing and evaluation a thermal behavior of the direct solar-electrical dryer requirmentes knowledge an important parameter such as adata on the ambient air temperature, air speed, humidity of ambient air and solar radiation.

Figs. (2–4) showed the trial run for three days under three air velocity indicated that the maximum temperatureis achieved afternoon while the maximum radiation is reached at 12 noon. The moisture decrease inside the dryer.The diffreance between ambient air and input dryer temperature were (2.6~30.7^{o}c), (2.7~33.4^{o}c) and (2.5~34.9^{o}c) for air speed 0.4,0.5 and 0.6 m/s on the practical trial as they depending on weather factors.Its noticed that increased air velocity decreased the dryer temperature.

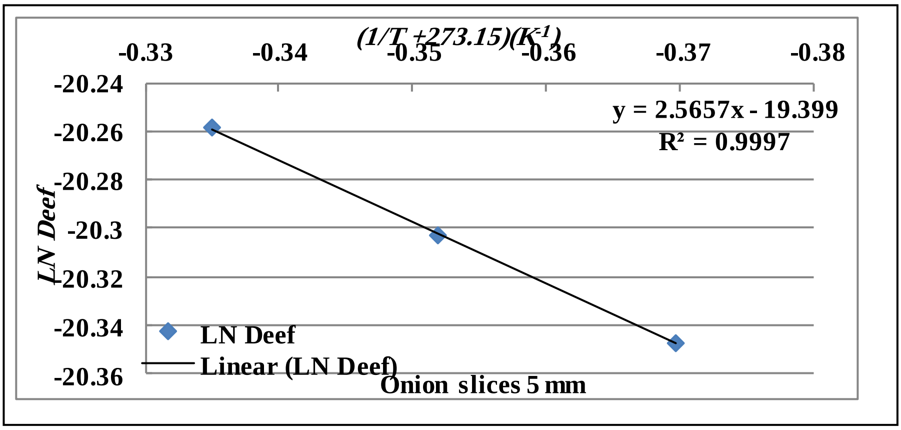

Fig. (2): Solar radiation and temperature variation of different elements of the collector on 19/9/2018.

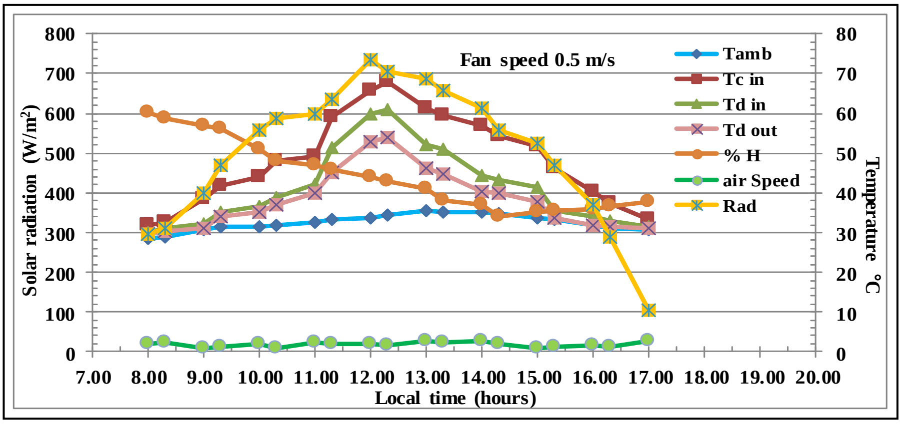

Fig. (3): Solar radiation and temperature variation of different elements of the collector on 20/9/2018.

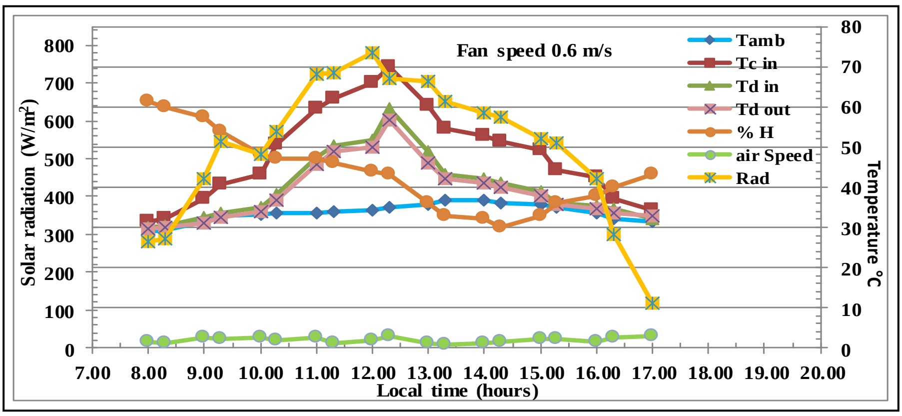

Fig. (4): Solar radiation and temperature variation of different elements of the collector on 21/9/2018.

Collector efficiency (%ɳ):-

Figure (5). 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 hight 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 (14.86% to 43.42%),(15.23% to 59.41%) and (14.07 % to 73.43%) at air speed 0.4, 0.5 and 0.6 m/s respectively so that velocities 0.6 m/s is better comparing 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.

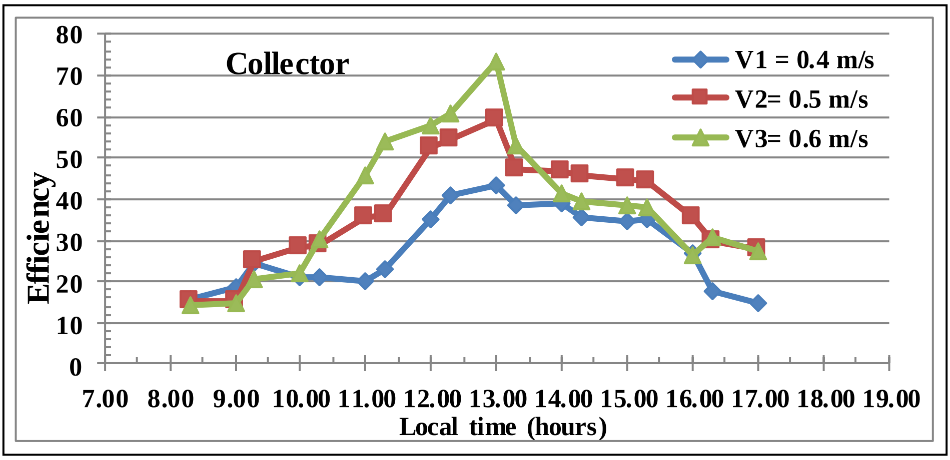

Fig. (5): Daily collector efficiency versus velocity and local time.

Dryer efficiency (%ɳ): -

The daily dryer efficiency given in Fig. (6) and it were ranged from(3.27% to 30.62%),(1.43% to 39.04%) and (0.39% to 44.25%) at air speed 0.4, 0.5 and 0.6 m/s respectively. It observed the system dryer efficiency for air speed 0.4 m/s 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 1.7 to 37.97%. 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.

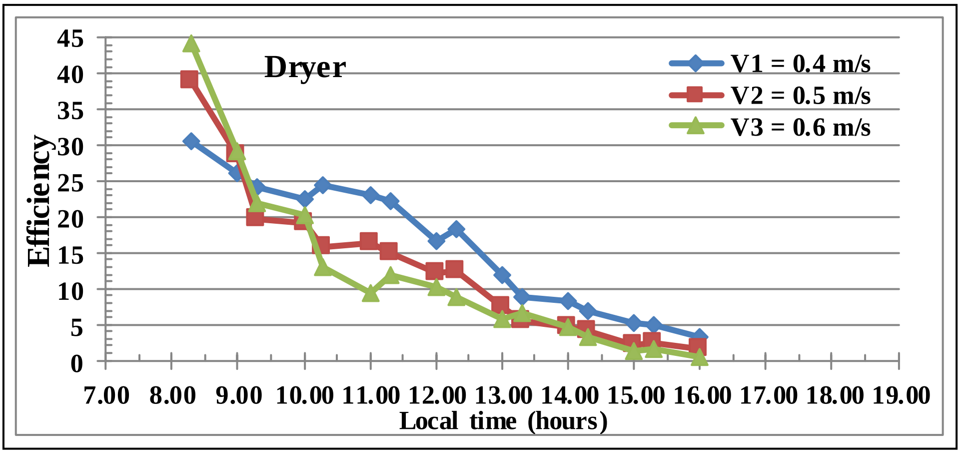

Fig. (6): Daily collector efficiency versus velocity and local time.

Effect of temperature and velocity on moisture content of red onion slices:-

Fig.(7) present relation between moisture ratio and drying time for three air speed rates were 0.4, 0.5 and 0.6 m/s and control respectively.

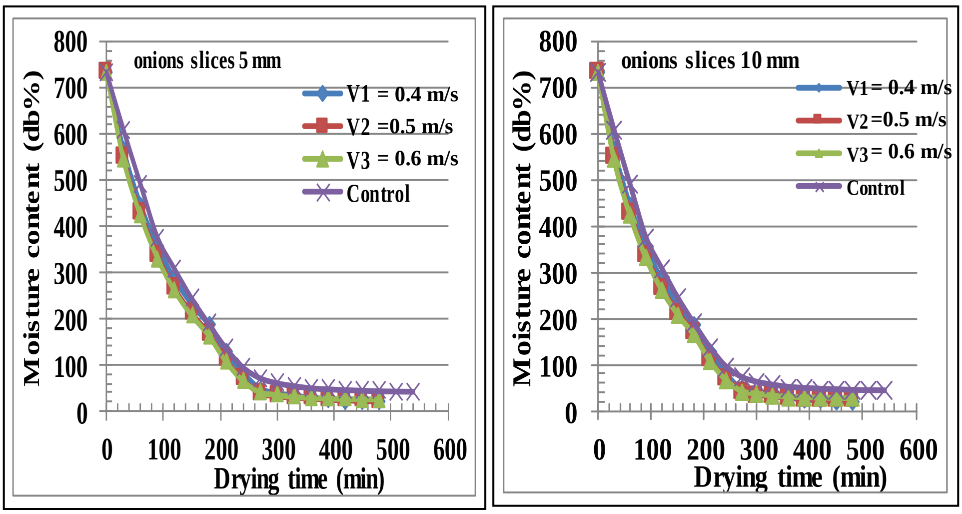

Fig. (7): Effect of temperature and velocity on red onions slices 5 & 10 mm drying of various times.

The moisture ration differed with the air speed rates in the dryer. This difference can be explained by decreasing air temperature from 43.81, 42.37and 40.82 for air speed 0.4, 0.5 and 0.6 m/s depending on the climatic conditions in the experiment day. So that increasing air temperature decreased significantly the moisture ratio from (11.11, 13.63 & 16.27% db) for onion slices 5mm while it were(19.04%, 21.95% & 26.26% db) Also an increase in air velocity from 0.4 to 0.6 m/s increases moisture ratio due to surface drought phenomenon. From the energy point of view it is preferable in drying operation to use low airflow rate which decreased significantly the moisture ratio (Boughali et al 2009)

Drying rate of sliced red onions slices 5 & 10 mm:-

In our experimental conditions, the samples show that drying rate took place only in the falling rate period and no constant stage was observed in drying curves Fig. (8).

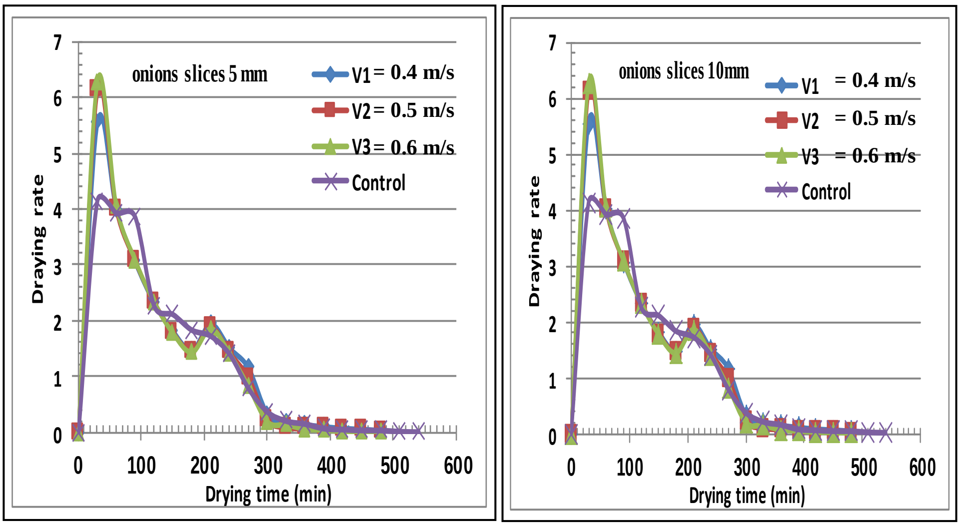

Fig. (8): Effect of drying rate for onions slices 5 & 10 mm drying of various times at velocity 0.4, 0.5 and 0.6 m/s.

When the temperature inside the dryer increases the drying rate well be 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 results showed that the higher drying rate accompanying with air flow rate 0.6 m/s compering with the other velocities in the first drying stage while it decreased in the second stage. This implied meaning that a film of water did not exist at the surface of the crop and moisture transfer from the interior of the product to its surface is effectuated by several complicated mechanisms (liquid or vapor diffusion or capillary forces), due to high dehydration in the product surface which making difficulty in liquid diffusion in the second stage. These results are in agreement with the observations of some researchers. (Kolawole et al., 2007).

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 ranged from (0.9968 to 0.9940), (0.9963 to 0.9798) and (0.9927 to 0.9694) while onion slices 10 mm ranged from (0.9876 to 0.9682), (0.9818 to 0.9463) and (0.9867 & 0.9797) for air speed rates 0.4, 0.5 and 0.6 m/s respectively. Accordingly, all tested models for onions slices 5 mm Page and Modified page II 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 page, Modified page II for air speed rates 0.4, 0.5 and 0.6 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}):-

The determined values of effective moisture diffusion coefficient (D_{eff}) for all the drying temperatures calculated by the Eq.(7) according to the slope which was obtained by the linear fitting, which are presented in Figure (9).

$$\text{Slope} = \frac{\pi^2 D_{eff}}{4L^2} \longrightarrow (13)$$

The values of effective moisture diffusion coefficient are shown in Table (5); it can be observed that the D_{eff} of red onions slices 5 mm varied from1.46× 10^{-9} to 1.59× 10^{-9} m^2/s in the range of temperatures from 40.82 to 43.81 °C, while it were varied from 5.25× 10^{-9} to 5.72× 10^{-9} m^2/s of red onions slices 10 mm which suggests an increase of D_{eff} with the

Table (3) Statistical result of drying models for onions slices 5 mm at air speed (0.4, 0.5 & 0.6 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	-0.009416	-	-	0.994900	0.003093	0.036997	0.053731	-1.067929303
	T_2	5 mm	-0.009006	-	-	0.979800	0.006588	0.059724	0.078412	-1.825417505
	T_3	5 mm	-0.008616	-		0.969400	0.009054	0.071256	0.091924	-2.191694965
	$T_{atmo.}$	5 mm	-0.006625	-	-	0.931100	0.015827	0.097437	0.122260	-2.657199101
Page	T_1	5 mm	0.022541	0.859857	-	0.996800	0.000121	-0.000368	0.011597	0.010636748
	T_2	5 mm	0.027837	0.827641	-	0.996300	0.000155	0.001723	0.010249	-0.052648205
	T_3	5 mm	0.031777	0.801894	-	0.992700	0.000150	0.001945	0.011386	-0.059828766
	T atmo.	5 mm	0.033918	0.765280	-	0.977300	0.000442	0.003128	0.019817	-0.085303211
Modified page	T_1	5 mm	0.012149	0.859857	-	0.996800	0.000121	-0.000368	0.011597	0.010636748
	T_2	5 mm	0.013204	0.827641	-	0.996300	0.000155	0.001723	0.010249	-0.052648205
	T_3	5 mm	0.013554	0.801894	-	0.992700	0.000150	0.001945	0.011386	-0.059828766
	T atmo.	5 mm	0.012014	0.765280	-	0.977300	0.000313	0.003468	0.016679	-0.085303211
Modified page II	T_1	5 mm	0.358940	0.859857	-	0.996800	0.000121	-0.000374	0.011597	0.010801364
	T_2	5 mm	0.393215	0.829814	-	0.996300	0.000148	0.004255	0.011325	-0.130064881
	T_3	5 mm	0.419874	0.801894	-	0.992700	0.000150	0.001945	0.011386	-0.059812076
	T atmo.	5 mm	0.398320	0.765280	-	0.977300	0.000442	0.003137	0.019819	-0.085541103
Henderson and Pabis	T_1	5 mm	-0.009000	-	0.8275	0.984000	0.002764	-0.005309	0.048942	0.026382613
	T_2	5 mm	-0.009000	-	0.7117	0.984000	0.007499	-0.005309	0.080617	0.619532942
	T_3	5 mm	-0.009000	-	0.671	0.969400	0.009820	-0.005309	0.092252	0.92914112
	T atmo.	5 mm	-0.007000	-	0.577900	0.931100	0.014605	-0.037354	0.113938	1.018689654

Table (4) Statistical result of drying models for onions slices 10 mm at air speed (0.4, 0.5 & 0.6 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	10 mm	-0.008463	-	-	0.968200	0.000434	-0.005718	0.020161	0.022906234
	T_2	10 mm	-0.008149	-	-	0.946300	0.000786	0.019348	0.027144	-0.457511824
	T_3	10 mm	-0.007759	-		0.935600	0.001667	0.032024	0.039533	-0.760437832
	$T_{atmo.}$	10 mm	-0.005766	-	-	0.910200	0.005321	0.056666	0.070892	-1.124224503
Page	T_1	10 mm	0.007549	1.023123	-	0.987600	0.000423	-0.001853	0.019245	0.041952343
	T_2	10 mm	0.010252	0.972670	-	0.981800	0.000439	-0.001003	0.019604	0.023706866
	T_3	10 mm	0.011907	0.943489	-	0.979700	0.000429	-0.000183	0.019365	0.004344695
	T atmo.	10 mm	0.008245	0.969923	-	0.969900	0.000955	0.006618	0.029136	-0.131301432
Modified page	T_1	10 mm	0.008430	1.023123	-	0.987600	0.000842	-0.000644	0.027364	0.041952343
	T_2	10 mm	0.009014	0.972670	-	0.981800	0.000439	-0.001003	0.019604	0.023706866
	T_3	10 mm	0.009132	0.943489	-	0.979700	0.000429	-0.000183	0.019365	0.004344695
	T atmo.	10 mm	0.007105	0.969923	-	0.969900	0.000955	0.006618	0.029136	-0.131301432
Modified page II	T_1	10 mm	0.839709	1.023123	-	0.987600	0.000423	-0.001862	0.019248	0.042169821
	T_2	10 mm	0.903933	0.972670	-	0.981800	0.000439	-0.001000	0.019604	0.02363964
	T_3	10 mm	0.917870	0.943489	-	0.979700	0.000429	-0.000177	0.019364	0.004199119
	T atmo.	10 mm	0.717846	0.969923	-	0.969700	0.000955	0.006609	0.029131	-0.131115826
Henderson and Pabis	T_1	10 mm	-0.008000	-	0.9594	0.968200	0.000686	0.000231	0.024506	-0.005236397
	T_2	10 mm	-0.008000	-	0.8595	0.946300	0.002670	-0.016804	0.048330	0.397368424
	T_3	10 mm	-0.008000	-	0.8124	0.935600	0.004501	-0.029261	0.062754	0.694830778
	T atmo.	10 mm	-0.006000	-	0.748100	0.910200	0.009230	-0.035978	0.090578	0.713785238

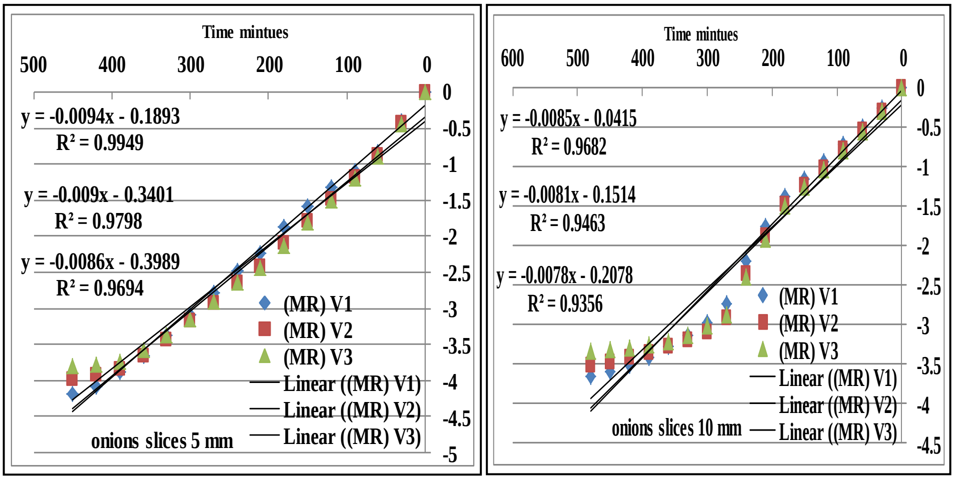

Fig. (9). Experimental logarithmic moisture ratio (MR) in function drying time for drying red onions slices 5 & 10 mm.

Table (5):-Moisture diffusivity for red onions slices at various speeds and drying temperature.

Air speed	Thickness	Average Temp.	Diffusivity coefficient (D_{eff}) m^2/s
0.4 m/s	**5 mm**	**43.81**	**1.59×10^{-9}**
	10mm		**5.72×10^{-9}**
0.5 m/s	**5 mm**	**42.37**	**1.52×10^{-9}**
	10mm		**5.51×10^{-9}**
0.6 m/s	**5 mm**	**40.82**	**1.46×10^{-9}**
	10mm		**5.25×10^{-9}**

drying temperature raised, the higher the drying temperature, the greater the rate of moisture diffusion. This phenomenon can be attributed to the increase of the vapor's pressure inside the samples, which would lead to the rapid movement of water at elevated drying temperatures (Shi et al., 2013).

Computation of activation energy (Ea):-

The activation energy (Ea) is a measure of the effect on the diffusion coefficient, and can be obtained from experimental data of the effective diffusivity. Figure 7 presents a plot of the logarithm of D_{eff} versses of The diffusivity constant (D_o) and activation energy (Ea) calculated from the linear regression. The D_o were (3.76×10^{-9}&1.35×10^{-9}) and Ea were (21.33 &19.14 kJ/mol) of red onions slices 5&10 mm.The values of the activation energy lie from 12.7 to 110 kJ/mol for most food materials (Zogzas 1996). The relationship between the activation energy and onions

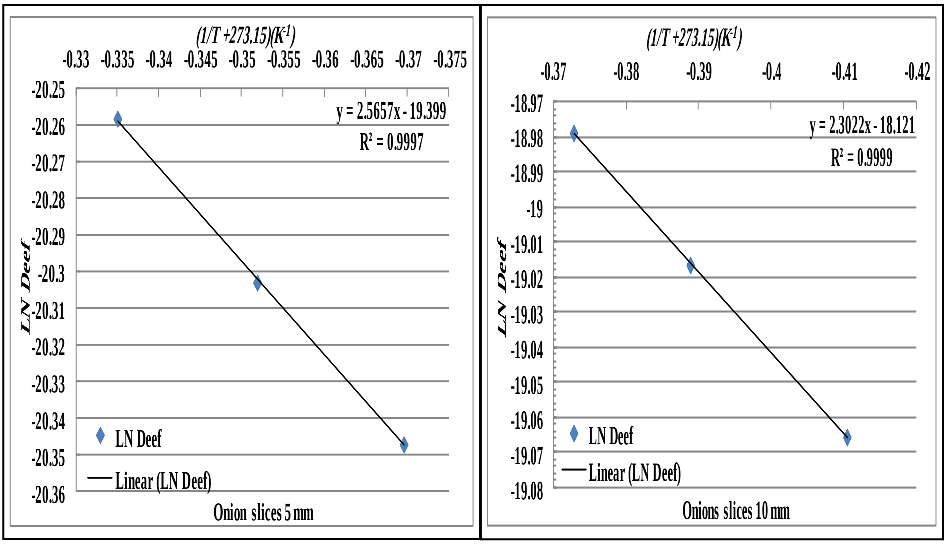

Fig. (10). Variation of effective diffusivity as function of temperature for red onions slices 5 & 10 mm.

thickness was found by regression analysis. The results indicated that the power equation can predict Ea based on the thickness. In the present study, the activation energy of red onions slices 10 mm was slightly lower, probably because the higher amounts of water were obtained during the bitterness elimination processing, and caused the bounded water to be relatively weaker than red onions slices 5 mm(Qing-An Zhang et al 2016).

Rehydration Characteristics:-

The rehydration ratio of dried red 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 red onions. Higher rehydration ratio indicates better product. The rehydration ratio ranged from 2.15 to 2.58% for onion slices 5 mm while it were ranged from 1.97 to 2.36% for onion slices 10 mm for different air flow. The slices were having greater rehydration ratio was combined to air speed 0.5 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).

Table (6):- Rehydration Characteristics of onions slices at various air speed rates.

Air speed	Thickness	RR	COR
0.4 m/s	5 mm	2.58	0.344
	10mm	2.36	0.337
0.5 m/s	5 mm	2.44	0.333
	10mm	2.22	0.325
0.6 m/s	5 mm	2.35	0.328
	10mm	2.16	0.327
Sun dry	5 mm	2.15	0.311
	10mm	1.97	0.317

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 (1.84 years) extend to return the investment cost because the small quantity produced by the dryer due to its small size. The life of the dryer (25 years), so the dryer will dry product free of cost for almost its entire life period.

$$\text{Payback period} = \frac{3000}{1628} = 1.84 \text{ years.}$$

CONCLUSION

1- The average daily dryer efficieny arrived to 16.98, 19.04 and 22.43 % for air speed 0.4,0.5 and 0.6 m/s respectiviely.

2- page, and Modified page II was selected as a suitable model to drying red onions slices (5 & 10 mm) respectiviely.

3- The Effective moisture diffusivity varied from 1.46× 10-9 to 1.59× 10-9 m^2/s and 5.25× 10-9 to 5.72× 10-9 m^2/s for red onions slices (5 & 10 mm) respectiviely.

4- The activation energy value of 21.33 kJ/mol and 19.14 kJ/mol for red onions slices 5&10mm) respectively.

5- The payback period for is dryer incubator were1.84 years.

6- The rehydration ratio of dried red onions slices 5 mm ranged from 2.15 to 2.58 % while it was ranged from 1.97 to 2.36% for 10 mm respectively.

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الملخص العربى

تصميم وتقييم مجفف شمسي- كهربائى مباشر لتجفيف شرائح البصل الأحمر

د. وليد محمد حنفى شحاته* و د. حسن حافظ طربای*

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 الاحمر سمك ٥و١٠مللى واشتملت تلك الوحدة على مجفف شمسى مباشر عبارة عن صندوق معدنى مزدوج الجدران بابعاد ١×٠,٥×٠,٣ (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 المجفف 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 درج معدنى قاعدتة من السلك تستخدم كصينية تجفيف يوضع عليها شرائح البصل المراد تجفيفه حيث يتم سحب الهواء الى المجفف بواسطة مروحة كهربائية قدرة ٥ وات بثلاثة سرعات مختلفة وهى ٠,٤ ، ٠,٥ و ٠,٦ م / ث وقد تم إجراء هذا البحث لحساب افضل موديل تجفيف وافضل سرعة هواء لاجراء عملية التجفيف و كفاءة المجفف و فاعلية الانتشار الرطوبى و طاقة التفعيل ونسبة الاماهة.

و قد تبين من النتائج المتحصل عليها كل مما يأتي :

١ - كانت متوسط كفاءة المجفف اليومية إلى 16.07 ، 12.83 و 12 ٪ لسرعة الهواء ٠,٤،٠,٥ و ٠,٦ م / ث على التوالي.

٢- كانت معادلة Modified Page II, Page افضل نموذج لمحاكاة تجفيف شرائح البصل ٥ و ١٠ مللى.

***مدرس بقسم الهندسة الزراعية - كلية الزراعة والموارد الطبيعية – جامعة اسوان.**

٣- تراوحت انتشار الرطوبة الفعال من ١,٤٦ × ١٠-٩ إلى ١,٥٩ × ١٠-٩ م ٢ / ثانية ومن ٥,٢٥ × ١٠-٩ إلى ٥,٧٢ × ١٠-٩ م ٢ / ثانية لشرائح البصل الأحمر (٥ و ١٠ ملم) على التوالي.

٤- قيمة طاقة التنشيط ٢١,٣٣ كيلو جول / مول و ١٩,١٤ كيلو جول / مول لشرائح البصل الأحمر ٥ و ١٠ ملم) على التوالي.

- فترة الاسترداد للمجفف كانت ١,٨٤ سنة.

- تراوحت نسبة الإماهة لشرائح البصل الاحمر المجفف ٥ مللى من ٢,٣٥ إلى ٢,١٦٪ بينما كانت من إلى ٢,٣٦٪لسمك ١٠ مللى.