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Drying of Onion Slices Using Hybrid Solar Dryer

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ABSTRACT

This study was proceeded to adjudge a hybrid solar drying system for drying onion slices. Experimental work was proceeded under different levels of air temperature “50, 60 and 70°C”, and thickness of onion slices “2, 4 and 6 mm” at constant air velocity of 0.32 m/s. The experimental measurements included onion slices moisture content, air temperature, solar energy flux incident, thermal drying efficiency and quality changes of the dried onion. Two different drying models “Lewis’ model and Henderson and Pabis's model” were also mathematically analyzed to describe the drying behavior. The results show that, the solar collector of the dryer could increase the air temperature inside the plenum chamber by 7.58 to 8.46 °C. The reduction in onion moisture content increased by increasing of air temperature and decreasing of slice thickness. The overall thermal efficiency of the tested dryer ranged from 22.9 to 34.7% and the solar collector provided “87.74, 78.83 and 67.46 %” of the total heat energy consumption to raise up the air temperature to the levels of “50, 60 and 70 °C”, respectively. Both examined models could describe the drying behavior of onion slices satisfactorily, but Lewis’ model was more precise. Quality evaluation tests showed that the rehydration ratio ranged from 3.95 to 5.53 for the treated onion and from 4.37 to 5.6 for the un-treated samples. Also the treated samples showed higher thiosulphinate content than the un-treated samples. While the increase in drying temperature and slice thickness resulted in higher reduction of ascorbic acid content.

Keywords: onions, dried onions, solar drying, hybridsolar drying

INTRODUCTION

Onion (A*llium cepa)* is amung the most popular vegetables and the oldest herb cultivated in many countries. It could provide many health benefits. It has also used as a good medicinal compound for cataract, cardiovascular disease and cancer due to its hypocholesterolemic, thrombolitic and antioxidant effects. Onion contains vitamin B, a trace of vitamin C, iron and calcium. The outstanding characteristic of onion is its pungency, which is due to a volatile oil known as allyl-propyl disulphide (Gouda, *et al.*, 2014).

According to (FAO, 2018), the onion world production is about 96.77 million tones yielded from 12 million feddans area.

The Egyptian total production is 2.958 million tons resulted of 194092 feddans (15.24 ton/feddan) Agricultural Statistics (2018).

Drying is a method of food preservation consists of vaporization of water and reduction of mass of a material. Dried products have a long storage life, and their transportation does not need a high energy. Onion flakes or powder are in extensive demand in several parts of the world which used as flavor in many meals (Mitra et. al, 2012).

In Egypt natural sun drying for preserving food and agricultural crops

has been practiced since ancient times. Conversely, this process has many disadvantages, i.e., products get spoiled due to rain, wind, moisture, and dust; loss of produce due to birds and animals and deterioration of the harvested crop due to putrefaction, insect attacks, and fungi (Hossain *et al*., 2008).

According to Mortezapour *et al.*, (2017), solar drying, is the most recommendable way to dry agricultural products, particularly in the poor countries. However, as low intensity of solar radiation, as low energy performance of the conventional solar collectors which make removing moisture from crops with solar dryers a waste of time procedure.

Recently, several researchers have worked on providing more effective solar collector designs combined with thermal storage systems, auxiliary heaters, as a hybrid sun dryer to maximize the advantage of solar driers. (Fudholi, *et al*., 2015).

The current study aims at testing and evaluating a hybrid solar dryer (with auxiliary heaters) for drying onions slices. The effect of air temperature and slices thickness on drying characteristics of onion was also examined and the quality changes of dried onion was assessed and evaluated.

MATERIALS AND METHODS

Materials:

The (Beheri) onions available in the local market was assigned for the experimental work. It was obtained from a local producing farm in Dakhlia governorate. The initial moisture content of the freshly harvested onion was ranged from (83– 86% (w. b.)).

Onion slices were divided into two subsamples. First sample was dipping in a solution containing 1% potassium meta-bisulphite and 1% citric acid for 5 min and coded as

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(T_1), and the second sample left without any pre-treatment and coded as (T_2).

Experimental Set-Up:

A hybrid solar dryer with auxiliary electric heaters (Fig. 1) was used for the experimental work. The dryer is a forced convection solar dryer consists of drying chamber constructed of an iron foundation with dimensions (1000wide, 2000 mm long and 1000 mm high) and a door of 700 x 450 mm located at the front side of the dryer for loading, unloading and collecting samples of onion. An iron frame with semi spherical was fixed over the drying chamber foundation and covered with a layer of polycarbonate sheet with an effective transmittance of 90 %.This part working as secondary solar collector for re-heating the air after passing through the onion slices to enhance its exhaust out of the dryer. Two axial flow fans were fixed at the top of the drying chamber on each side of the semi spherical iron frame for suction of the wet air passed through the drying bed. A solar collector was installed on the side of the dryer. It was consists of an aluminum frame of 2920 mm long, 1000 mm wide and 250 mm high. The surface area of the collector covered by polycarbonate sheet with effective transmittance of 90 %. A corrugated black painted aluminum sheet was fixed between the upper and bottom surfaces of the collector to increase the efficiency of energy collection and to allow the drying air to contact with both sides of the absorber plate. The collector's slope was set at 30° with the horizontal level which calculated according to the location of the dryer (The average optimum tilt angle for all months for the Department of Agricultural Engineering, Faculty of Agriculture, Mansoura University).

A blower powered by a 0.367 kW electric motor spinning at 3000 rpm used for plowing the heated air into the drying chamber. It was controlled by a vertical gate to provide the desired level of air velocity required for drying the sliced onion.

An auxiliary electrical heater with a power of 6 kW electric heaters was used for increasing the drying air temperature to the desired levels particularly at the adverse conditions and low intensity of solar radiation.

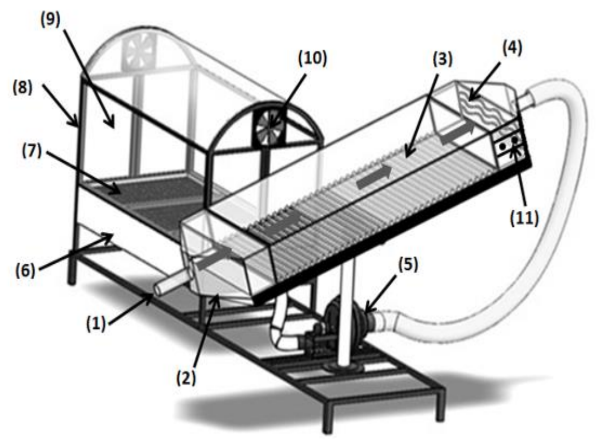


Fig. 1. A schematic for the tested hybrid solar dryer with auxiliary heaters.

1- Air inlet 2- Solar collector 3- The absorber plate 4- The auxiliary heaters 5- Air blower 6- Plenum chamber 7- Drying tray 8- Drying chamber 9- Loading door 10- Axial suction fan 11- Digital thermostat

Experimental treatments:

The experimental treatments included the following factors:

1-Two pre-treatments of onion slices included (treating with a solution containing 1% potassium meta-bisulphite, 1% citric acid for 5 min and untreated samples).

2- Three distinct temperatures for the incoming air (50, 60, and 70°C).

3- Three distinct thickness of onion slices (2, 4, 6 mm) with a constant air velocity of 0.32 m/sec.

Experimental Measurements and Instrumentation:

1. Onion moisture content:

The initial and final moisture contents of onion slices were determined using the method described by A.O.A.C. (1995) using an electric oven at 70°C for 16 hours.

2. Air velocity:

A digital air velocity instrument connected with a velocity probe model (9515) used to obtained velocity of thrusted air over the drying trays.

3. Air temperature and relative humidity:

A temperature and relative humidity meter model HT-315 was used for measuring both parameters of the drying air during the experimental work.

4. Solar energy measurement:

The solar radiation meter model SPM-1116SD was used for measuring the solar radiation flux incident during the experimental work.

Experimental procedure:

Prior to each drying run, the dryer auxiliary heaters were adjusted for the required level of drying air temperature. After the dryer working at stable condition, the dryer tray was loaded with the onion slices which were distributed uniformity in a single layer. The dryer tray was divided into six equal parts to accommodate the samples of onion representing two onion conditions (treated slices and un-treated slices) in three replicates for each condition.

Weight changes of samples were recorded every 15 min for the first two hours, every 30 min for the next two hours and then every hour until the end of experimental run.

The drying process was stopped when there was no noticeable change in the weight of onion samples.

Drying Models for Simulating the Drying Data:

In this study Lewis' model and Henderson and Pabis's model were used to describe thin layer drying of onion slices.

1. Lewis' model:

$$MR = \frac{M-M_f}{M_0-M_f} = \exp(-K_L t) \quad \text{(1) (Lewis, 1921).}$$

2. Henderson and Pabis's model:

$$MR = \frac{M-M_f}{M_0-M_f} = A \exp(-K_H t) \quad \text{(2) (Henderson and Pabis,1961).}$$

Where:

MR: Moisture ratio, dimensionless.
M: Moisture content at time t, (%, d.b.)
M_0: initial moisture content, (%, d.b.)
M_F: Final moisture content, (%, d.b.)
K_L: Drying constant for Lewis' model, (min^{-1})
t: Drying time, min
K_H: Drying constant for Henderson and Pabis's model, (min^{-1})
A: Constant, dimensionless.

Thermal efficiency of solar collector:

Solar energy available (Q):

$$Q = R \cdot A_c, \quad \text{Watt} \qquad (3)$$

Absorbed solar energy (Qa):

$$Qa = \tau .\ \alpha .\ R.\ A_c, \quad \text{Watt} \qquad (4)$$

Absorbtion efficiency (η_a):

$$\eta_a = \frac{Q_a}{Q} \quad \% \qquad (5)$$

Useful heat gain (Q_c)

$$Q_c = m_a.\ C_p.\ (T_{ao} - T_{ai}), \text{ Watt} \qquad (6)$$

Heat transfer efficiency (η_h):

$$\eta_h = \frac{Q_c}{Q_a} \times 100 \quad ,\% \qquad (7)$$

Solar collector heat losses (QL):

$$Q_L = Q_a - Q_c, \text{ Watt} \qquad (8)$$

Overall thermal efficiency of solar collector (η_o):

$$\zeta_o = \frac{Q_c}{Q} \ , \% \qquad (9)$$

Where:

R: Solar energy flux incident on the surface of solar collector, (W/m^2)
Ac: Surface area of the solar collector, (m^2)
τ: effective transmittance of solar collector cover system, decimal
α = effective absorptance of the absorber plate of collector, decimal
m_a: mass flow rate of air, (kg/s).
C_p: specific heat of air, (J/kg/ ^oC).
T_{ao}: outlet temperature of air, (^oC).
T_{ai}: inlet temperature of air, (^oC).

Thermal efficiency of the solar dryer:

The ratio of useful heat energy required for evaporating moisture (Q_{ev}) to the available heat (Q_I) is defined as the efficiency of the solar drying system (η_{thd}). It could be calculated according to **(Abdelatif, 1989)** as follows:

$$\eta_{thd} = (Q_{ev} / Q_I) \times 100 \quad , (\%) \ \ldots\ldots\ldots\ldots\ldots(10)$$

$$Q_{ev} = m_{ev}\ L \quad , (kJ) \ \ldots\ldots\ldots\ldots\ldots (11)$$

$$Q_I = Qu + Q_E \quad , (kJ) \ \ldots\ldots\ldots\ldots\ldots (12)$$

Where:

m_{ev} = Mass of moisture removed, (kg).
L = Latent heat of vaporization of water, (kJ/kg).
Q_E = Electric energy of heaters, (kJ).
Q_U = Useful heat gain by the solar collector, (kJ).

Quality evaluation of the dried onion

The measured quality of dried onion slices included Flavor in terms of thiosulphinate content (TC) using the method cited by (Kaymak-Ertekin *et al.* 2005), The color changes of the onion slices (anthocyanins or non-enzymatic browning determination) using the method of Garzón, *et al.*, (2009), Vitamin C or Ascorbic acid content using the method of Ranganna (1986) and Rehydration Ratio was calculated by the method of Itoh and Chung (1995); Fasina et, al. 1997).

RESULTS AND DISCUSSION

1. Solar radiation flux incident:

The hourly average solar radiation available during the experimental work at the period from 6 to 27 August 2018 in Mansoura, Egypt was measured and recorded. The hourly average available solar radiation was 563.4 W/m^2. Fig (2) shows the measured solar energy flux incident during the experimental work. In general, the solar radiation gradually increased from sunrise till it reached the maximum value of 880 W/m^2 at noon, it then decreased gradually until it reached the minimum value of 40W/m^2 at sunset.

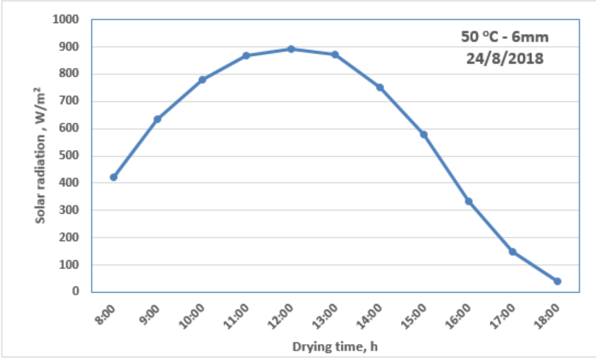


Fig. 2. Solar radiation flux incident outside the solar collector as related to day time during the experimental period at drying air temperature (50 ºC).

2. Air temperature inside the hybrid solar dryer:

Figs (3) and (4) present the air temperature profile at different positions outside and inside the examined solar dryer.

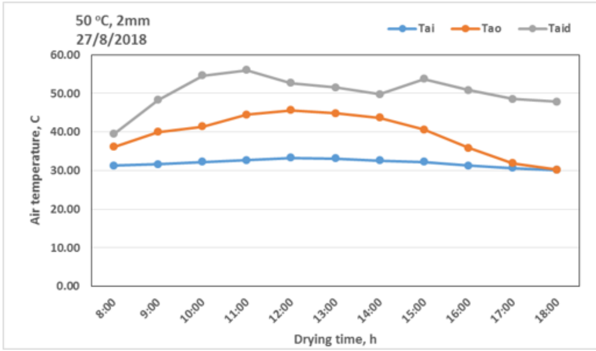


Fig .3. Air temperature at different positions of the dryer as related to drying time at drying air temperature (50 °C).

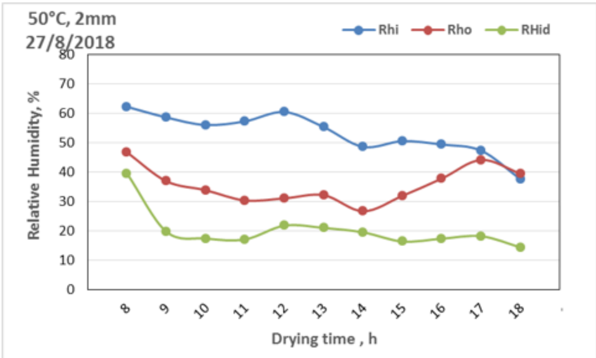


Fig. 4. Air temperature at different positions as related to drying time at drying air temperature (70 °C).

Where:

$T_{ai:}$ Ambient air temperature.
$T_{ao:}$ Solar collector air temperature.
$T_{aid:}$ Plenum chamber air temperature.

As shown in the figures, at the minimum air temperature of 50 °C and slices thickness of 2, 4 and 6 mm, the measured ambient air temperature during the experimental work were 31.91, 32.23and 32.30 ^{O}C and the corresponding relative humidity 53.09, 45.74 and 42.5% respectively. As the air pass through the main solar collector, the air temperature increased to 39.52, 40.19 and 40.25 ^{O}C and the relative humidity decreased to35.62, 30.34 and 28.25% respectively. The air temperature was further increased as it passes through the auxiliary heaters and approached levels of 50.3, 51.37 and 50.14 ^{O}C with relative humidity 20.29, 16.83 and17.65% respectively.The above-mentioned results revealed that, the solar collector of the dryer could increase the air temperature inside the plenum chamber by about 7.61, 7.96 and 7.95 ˚C, respectively. While, at the maximum air temperature of 70 °C and slices thickness of 2, 4 and 6 mm, the measured ambient air temperature during the experimental work were 31.87, 31.23 and 31.93 ^{O}C and the corresponding relative humidity45.87,40.28 and 42.26% respectively. As the air pass through the main solar collector the air temperature increased to 39.45, 39.69 and 39.67 ^{O}C and relative humidity decreased to 30.76, 25.9 and 28.46% respectively. Meanwhile the air temperature was further increased as it passes through the auxiliary heaters and approached levels of 72.26, 71.60 and 72.85 ^{O}C with relative humidity 6.67, 5.73 and 5.8%respectively. In general,The above-mentioned results revealed that, the solar collector of the dryer could increase the air temperature inside the plenum chamber by 7.58 to 8.46 ˚C.

3. Change in onion slices moisture content

The reduction in onion slices moisture content was varied and increased due to increasing drying air temperature and the reduction of slices thickness. The constant drying rate period wasn't noticed for most of experiments, while all the drying process occurred as falling rate-drying period as shown in fig (5).

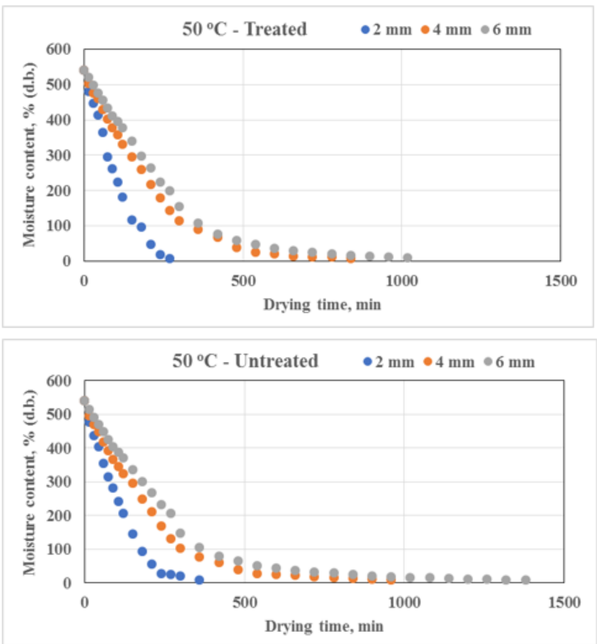


Fig. 5. Changes in moisture content as related to drying time at different slices thickness for the treated and un-treated onion slices at (50 °C).

Thin Layer Drying Equations

The drying constant (kL) for Lewis' model (3.1) could be obtained from the slope of the logarithmic relationship between Ln (MR) vs drying time (t) as shown in Fig(6) and Table (1).

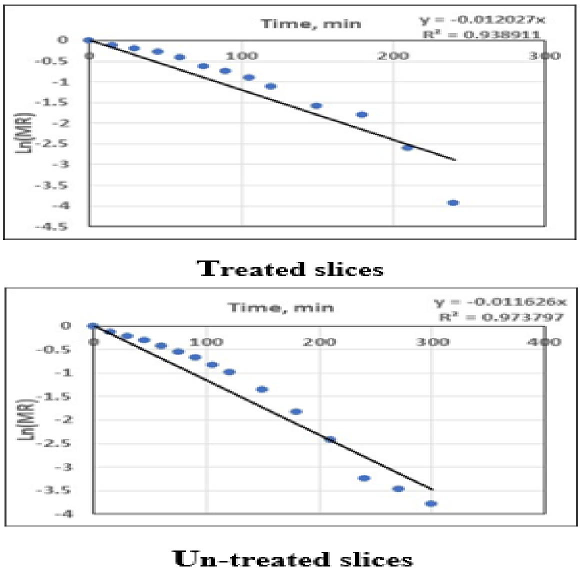


Fig. 6. Determination of constant (kL) of Lewis' model at (Ta) 50 °C and (Th) 2 mm for the treated and un-treated slices.

Table 1. values of the constant (k_L) for Lewis' equation at different levels of drying air temperature and slices thickness.

Slice thickness, (mm)	Drying air temperature, °C					
	Treated			Un-treated		
	50	60	70	50	60	70
2	0.012027	0.016135	0.017409	0.011626	0.017209	0.019684
4	0.006170	0.007496	0.012606	0.005640	0.006796	0.010523
6	0.004928	0.006137	0.007406	0.004193	0.00504	0.005806

As shown in Table (1), the constant (k_L) increased by increasing of drying air temperature. However, it has decreased by increasing of slice thickness for Henderson and Pabis's model. Fig. (7), illustrates the relationship between the moisture ratio (MR) vs the drying time (t). The computed values of the drying constant (kH) are listed in Table (2).

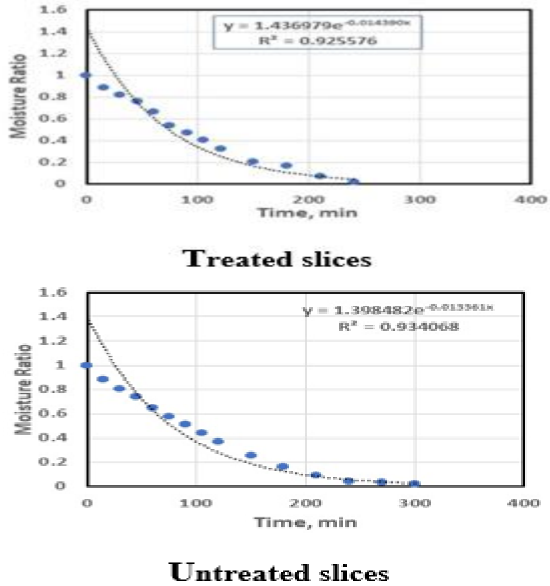


Fig .7. Determination of constants (kH) and (A) of Henderson and Pabis's model at (Ta) 50 °C and (Th) 2 mm for treated and un-treated slices.

Table 2. values of constant (kH) at different levels of drying air temperature and slices thickness for both treated and un-treated slices.

Slice thickness, (mm)	Drying air temperature, ºC					
	Treated			Un-treated		
	50	60	70	50	60	70
2	0.014390	0.019449	0.022546	0.013361	0.019757	0.022027
4	0.006741	0.009140	0.015171	0.005829	0.007702	0.012054
6	0.005278	0.006845	0.008600	0.004231	0.005244	0.006268

As shown in Table (2), the drying constant (k_H) increased by increasing of the drying air temperature and the decreasing of slices thickness.

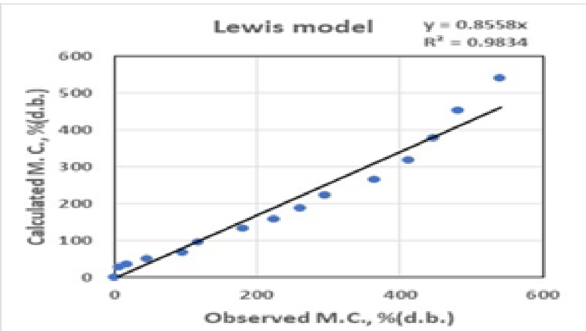
The constant (A) was also calculated for different combinations of drying parameter and presented in table (3). As shown in the table, the constant (A) also increased by increasing of the drying air temperature and decreased by increasing of slices thickness.

Table 3. Values of constant (A) of Henderson and Pabis's model.

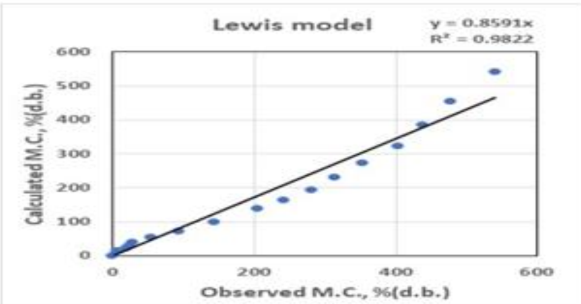
Slice thickness, (mm)	Drying air temperature, ºC					
	Treated			Un-treated		
	50	60	70	50	60	70
2	1.436980	1.559861	1.813378	1.398482	1.554880	1.947208
4	1.317071	1.512012	1.758188	1.112860	1.388053	1.469806
6	1.236353	1.492581	1.615445	1.032310	1.161135	1.249818

Fitting curves examining the most applicable model to simulate the drying data:

As shown in Figs. (8) and (9), both Lewis' and Henderson & Pabis's models described the drying behavior of onion slices satisfactorily with high values of coefficient of determination and low values of standard error (SE).

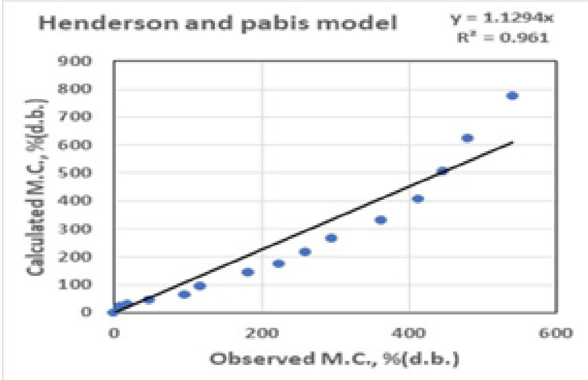


Treated slices

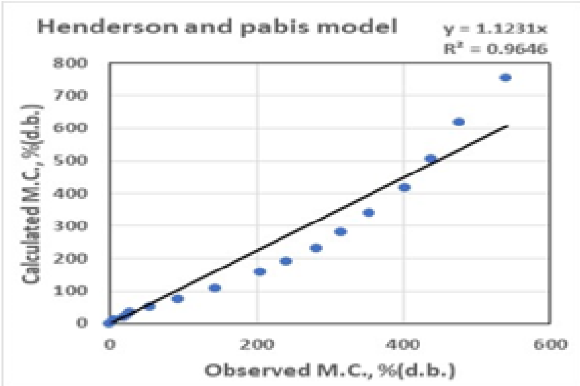


Untreated slices

Fig. 8. Calculated vs observed values of onion slices moisture content using Lewis' model at (Ta) 50°C and (Th) 2 mm.



Treated slices



Untreated slices

Fig. 9. Calculated vs observed values of onion slices moisture content using Henderson and Pabis's model at (Ta) 50°C and (T_h) 2 mm.

A comparative study was carried out for both models to assess the most applicable model to simulate and describe the drying behavior of onion slices under the studied range of experimental parameters.

The results showed that, Lewis' model and Henderson and Pabis's model obtained very close values of coefficient of determinations (R^2) and standard error (SE). This means that, both examined models could describe the drying behavior of treated and untreated onion slices satisfactory.

However, Lewis' model gets highest value of coefficient of correlation (r) and lowest values of chi-square ($\chi 2$), mean bias error (MBE), root mean square error (RMSE). So, it may conclude that, Lewis model was most proper model to describe the drying behavior of onion slices under examined conditions.

Thermal efficiency of the solar collector:

Table (4) shows the calculated thermal efficiency of the solar collector. As shown in the table the absorption efficiency of the solar collector ranged from 69.6 to 72.8% and the heat transfer efficiency ranged from 79.5 to 82.6%. While the overall thermal efficiency of the solar collector ranged from 63.1 to 65.2 %.

Table 4. Solar collector thermal performance and efficiency.

Date	Air temperature, C	Slices thickness, mm	solar radiation W/m2	Ambient air temperature, C	Solar collector temperature, C	Solar energy available Q, W	Absorbed solar energy Qa, W	absorption efficiency η_a	Useful heat gain Qc, W	Heat transfer efficiency, η_h	Solar collector heat losses, Ql, W	Overall thermal efficiency η_o
27/8/2018	50	2	546.765	31.91	39.52	1093.530	852.633	0.696	712.148	0.826	140.485	0.651
26/8/2018	50	4	582.710	32.23	40.19	1165.419	908.947	0.698	745.047	0.813	163.900	0.639
24/8/2018	50	6	573.917	32.30	40.25	1147.833	898.020	0.702	744.707	0.819	153.313	0.649
19/8/2018	60	2	589.551	31.59	39.71	1179.102	920.166	0.711	760.271	0.817	159.895	0.645
20/8/2018	60	4	498.228	31.52	38.34	996.457	776.085	0.709	638.540	0.813	137.545	0.641
21/8/2018	60	6	524.731	31.13	38.43	1049.461	822.629	0.707	683.750	0.820	138.879	0.652
8/8/2018	70	2	562.207	31.87	39.45	1124.414	874.658	0.726	709.800	0.795	164.858	0.631
6/8/2018	70	4	623.164	31.23	39.69	1246.329	969.915	0.728	792.405	0.809	177.510	0.636
7/8/2018	70	6	569.402	31.93	39.67	1138.805	886.183	0.727	724.500	0.807	161.683	0.636

Thermal and drying efficiency of the solar dryer:

Table (5) showed that, the overall thermal efficiency of the developed solar dryer with auxiliary heaters ranged from 22.9 to 34.7% and the solar collector provided 87.74, 78.83 and 67.46 % of the total heat energy consumption for air heating to the levels of 50, 60 and 70 °C, respectively.

Table 5. Thermal efficiency and energy consumption of solar dryer.

Drying air temperature, C	Slices thickness, mm	Useful heat gain by the collector, kJ	mass of moisture removed for treated samples, kg	Latent heat of evaporation for treated samples, kJ/kg	mass of moisture removed for untreated samples, kg	Latent heat of evaporation for untreated samples, kJ/kg	Total heat energy required for evaporation, kJ	Average heat energy gain by auxiliary heaters, kJ	Total heat energy consumed, kJ	average thermal efficiency of the dryer	average energy saving by solar collector	Average energy saving by solar collector
50	2	20045.340	1.250	2673.80	1.250	2625.600	6624.980	720	20765.330	31.900	96.530	
50	4	26821.700	1.667	2641.70	1.670	2581.800	8702.860	2880	29701.700	29.300	90.300	87.74
50	6	26809.440	2.290	2393.96	2.290	2601.420	11436.400	8280	35089.440	32.600	76.400	
60	2	17788.800	1.252	2814.10	1.251	2876.900	7123.670	2736	20524.800	34.700	86.700	
60	4	22987.500	1.666	2590.90	1.665	2554.670	8571.800	4680	27667.450	30.980	83.100	78.83
60	6	24614.900	2.289	2406.13	2.289	2659.450	11599.100	12312	36926.990	31.400	66.700	
70	2	16189.230	1.252	2926.13	1.252	2960.740	7371.660	15912	32101.230	22.900	50.400	
70	4	28606.800	1.667	2758.32	1.657	2463.100	8680.250	5328	33934.800	25.600	84.300	67.46
70	6	26082.010	2.291	2698.11	1.964	2585.840	11259.600	12528	38610.010	29.160	67.700	

Quality of onion slices:

1. Final moisture content:

The final moisture content (FMC) of the dried onions decreased with increasing temperature with both treated and untreated slices (Table 6). The effect of thickness on the final moisture content was more pronounced at higher temperature. FMC decreased slightly in the case of thinner slices. It can be noticed that the final moisture content of the dried onion slices under the studied conditions almost reached the recommended range of the dried onions 6-7% as reported in the literature (Sarsavadia, 1999). Since the moisture content of dried onion slices was well within the moisture content range of safe moisture level, further reduction was not required. It can be also noticed that the treatment of onion slices reduces the time required to reach the safe moisture content by nearly 25%.

Table 6. The final moisture content (% d.b) and the drying time (min) for treated and untreated onion slices at different drying temperature and slices thickness.

	Treated slices						Untreated slices					
Ta	**50 ºC**		**60 ºC**		**70 ºC**		**50 ºC**		**60 ºC**		**70 ºC**	
Th	**MC**	**Time**	**MC**	**Time**	**MC**	**Time**	**MC**	**Time**	**MC**	**Time**	**MC**	**Time**
2mm	6.64	270	5.89	240	5.76	210	6.76	360	6.15	300	5.87	270
4mm	7.02	840	6.94	480	6.66	420	7.22	960	7.12	660	7.09	480
6mm	7.28	1020	7.16	960	7.01	720	7.3	1380	7.23	1200	7.14	840

2. Rehydration ratio:

As shown in the fig.(10) the rehydration ratio ranged from 3.95 to 5.53 for the treated onion slices and between 4.37 and 5.6 for the un-treated slices. The permissible levels of the dried onions (R.R > 2.5) are recommended by(Adoga (2005) and Ranganna (2005).

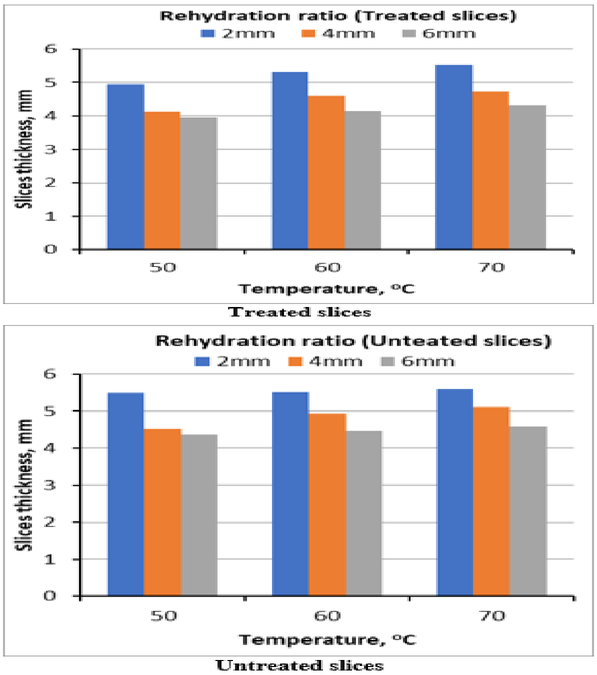


Fig. 10. The rehydration ratio of onion slices.

3. Thiosulphinate content:

As shown in fig (11), the increase in temperature resulted in a slight decrease in thiosulphinate content but the increase in thickness facilitated significantly higher thiosulphinate content. This was due to the fact that with higher thickness of slices the area exposed to the heated air per unit mass of onion was smaller and the proportion of thiosulphinate coming in direct contact with the heated air was substantially reduced. As a result, the treated samples showed higher thiosulphinate content than the untreated samples. It is evident that the thiosulphinate content can be maximized by involving the sulfite treatment and adopting a lower drying temperature and a greater slice thickness as mentioned by Mitra, et. al., (2011).

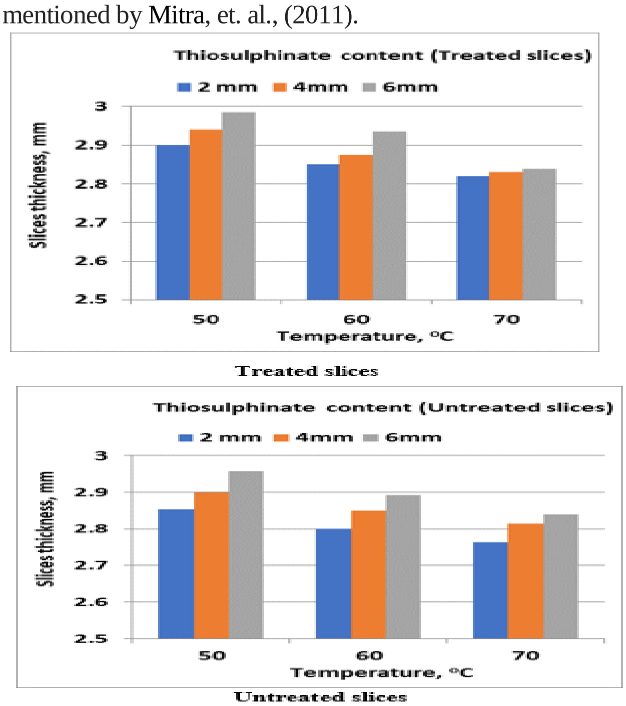


Fig.11. The changes in thiosulphinate content of onion slices.

4. Anthocyanin content:

As shown in Fig (12), the anthocyanin content varied from 61.84 to 69.73 for the treated onion slices and from 55.81 to 63.64 for the un-treated slices. It can be noticed that the anthocyanin values decreased faster at high temperature. On the other hand, greater thickness increased the drying time thereby exposing the slices to heated air for a longer time compared to thin slices. Therefore, the increase in temperature and thickness resulted in higher anthocyanin loss. However, the treated slices showed less anthocyanin reduction due to sulfite treatment.

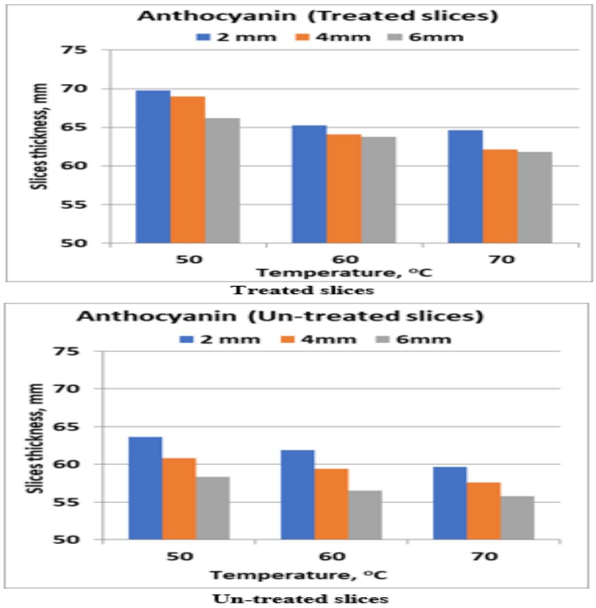


Fig. 12. The changes in anthocyanin of onion slices.

5. Ascorbic acid:

As shown in the Fig. (13), an increase in drying air temperature had a negative effect on ascorbic acid (Vitamin C).This is due to the breakdown of Vitamin C at high temperatures and the sensitivity of Vitamin C to heat. On the other hand, greater thickness increased the drying time thereby exposing the slices to the heated air for a longer time compared to thin slices. Therefore, the increase in drying temperature and thickness resulted in higher reduction in ascorbic acid.

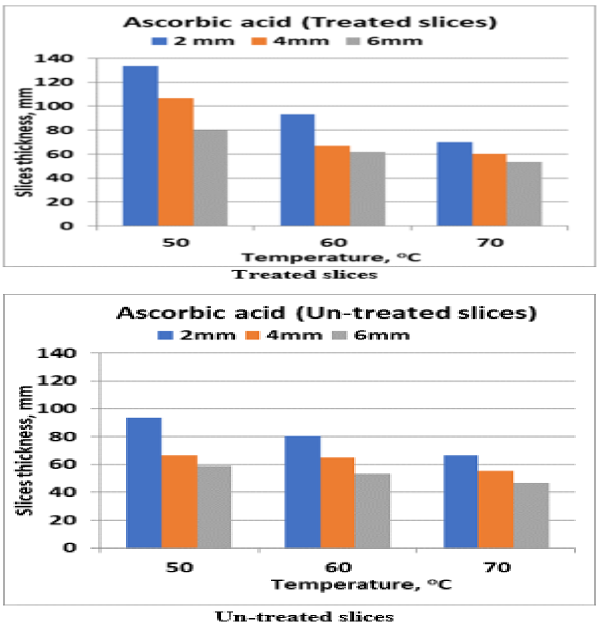


Fig.13.The changes in ascorbic acid of onion slices.

CONCLUSION

- The solar collector could increase the air temperature inside the plenum chamber by of 7.58 to 8.46 ^{O}C.
- The reduction in onion slices moisture content was varied and increased with the increase of drying air temperature and the reduction of slices thickness
-The treatment of onion slices reduces the time required to reach the safe moisture content by nearly 25%.
- The drying constants (k_L),((k_H) and (A) increased with the increase of drying air temperature and decreased with the increase of slice thickness.
- Lewis' and Henderson & Pabis's models could describe the drying behavior of onion slices satisfactorily. However Lewis model was the most proper in describing the drying behavior of onion slices.
- The overall thermal efficiency of the solar dryer ranged from 22.9 to 34.7% and the solar collector provided 87.74, 78.83 and 67.46 % of the total heat energy for air heating to the level of 50, 60 and 70 °C, respectively.
- The rehydration ratio ranged from 3.95 to 5.53 for the treated onion slices and between 4.37 and 5.6 for the un-treated slices, while the treated samples showed higher thiosulphinate content than the untreated samples. Also the increase in drying temperature and thickness resulted in a higher reduction in the ascorbic acid.

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تجفيف شرائح البصل باستخدام مجفف شمسي هجين

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أجريت دراسة لاختبار وتقييم مجفف شمسي من النوع الهجين المزود بسخانات كهربية لتثبيت درجة حرارة الهواء خلال فترة التجفيف. تم اجراء التجارب باستخدام ثلاث مستويات مختلفة من درجة حرارة هواء التجفيف 70,60,50 درجة مئوية ، ثلاث مستويات مختلفة من سمك شرائح البصل 6,4,2 مم وسرعة ثابتة لهواء التجفيف0,32 م/ث للشرائح المعاملة والغير معاملة . وشملت القياسات التغير في المحتوي الرطوبي للبصل ،ودرجة الحرارة والرطوبة النسبية للهواء الجوي وهواء التجفيف ،الطاقة الشمسية الساقطة ،كما تم قياس الكفاءة الحرارية للمجفف وكذلك التغير في خصائص جودة البصل المجفف .تم أيضا اختبار نموذجين رياضين للتنبؤ بالمحتوي الرطوبي لشرائح البصل أثناء فترة التجفيف هما (Lewis' model and Henderson & Pabis's model). وقد أظهرت النتائج ما يلي:- أمكن للمجمع الشمسي زيادة درجة حرارة الهواء الجوي بما يتراوح بين8,57 -8,46 درجة مئوية . - زاد معدل النقص في المحتوي الرطوبي لشرائح البصل بزيادة درجة حرارة الهواء وانخفاض سمك شرائح البصل. أدت المعاملة المبدئية لشرائح البصل الى خفض الزمن الكلي المطلوب للوصول الى المحتوى الرطوبي الأمن بنسبة 25% - أمكن لكل من معادلتي لويس وهندرسون وصف التغير في المحتوي الرطوبي لشرائح البصل بصورة مرضيه بينما كانت معادلة لويس أكثر دقة في وصف النتائج. - تراوحت الكفاءة الحرارية للمجفف الشمسي الهجين بين 22,9-34,7% بينما أمكن للمجمع الشمسي إضافة 67,64-87,74 % من اجمالي الطاقة الحرارية المستهلكة . - تراوحت قيم إعادة التشرب لشرائح البصل بين 4,37 – 5,6 بينما أدت زيادة درجة الحرارة الي ارتفاع طفيف في محتوي الشرائح من الثيوسلفانات في حين انخفضت قيم حمض الاسكوربيك بزيادة درجة حرارة الهواء وسمك الشرائح .