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DEVELOPMENT AND EVALUATION OF A SOLAR DRYER FOR THIN LAYER DRYING OF HAYANI DATE

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ABSTRACT

A study was carried out to test and evaluate a forced convection solar dryer with auxiliary electric heater and temperature control system during thin layer drying of date . During the experimental work the temperature of drying air was adjusted to be approximately constant at 40 , 50 , 60 and 70 °C and air velocity of 0.26 , 0.52 and 0.78 m/min. High moisture hayani date was dried under three different treatments of date (peeled date , peeled treated date and unpeeled date). Two empirical models (Exponential and Page) were examined to describe the drying behaviour and predict the change in moisture content of date during the drying process. Moisture content of date , thermal efficiency of the dryer and the total sugar and percentage reducing in sugars of the dried date were also determined. The obtained results showed that, both of the empirical models could satisfactorily be described the change in date moisture content during the drying process under specific conditions. On the other hand Page's model proved that it can predict and describe drying behaviour more adequately than the simple model . The dryer thermal efficiency increased with the increase of drying air temperature and air velocity and it ranged from 16.60 to 55.85 % .While the thermal efficiency of the solar collector ranged from 47.05 % to 83.79 %. Also, the total and reducing sugars decreased with the decrease of drying air temperature and air velocity and it ranged from 40.33 to 44.66 % d.b. for the reducing sugar and from 49.65 to 56.93 % d.b. for the total soluable sugar.

INTRODUCTION

Date palm (*Phoenix dactylifera* L.) is one of the major fruit tree in Egypt. Date fruits are consumed in large quantities in Egypt. Date is eaten at all stages of the fruit development (khalal, rutub, and tamr). In addition to direct consumption, dates are processed in many ways, such as , date paste and date syrup(depis) (Mohamed and Ahmed, 1981).

Egypt is one of the countries , which has solar energy in abundance. It lies within the tropical and sub-tropical regions. It has a value of about 2.2 to 9.4 kW of solar energy per square meter per day, and sunshine duration per year extended from about 3000 to 4000 hours (Abdelatif, 1989).

In Egypt, natural sun drying is one of the common ways to conserve agricultural products. Considerable losses may occur during natural sun drying due to various influences, such as rodents, birds, insects, rain, storms and microorganisms .

Farmers harvest soft varieties of date before complete ripening stage or (rutab stage) and they are whether start marketing their product as fresh date in cheap price, or dry the product under sunshine (traditional methods) by spreading them on mats in the open air being directly exposed to solar radiation. This method is obviously not satisfactory as dust, dirt, rodents and insects can not be eliminated. On the other hands even this method has the advantage of non energy consumption, the total cost become high because of slow drying rate, long drying period and the need of large number of workers for frequent turning up the bed of date during the drying process and covering it during night time... etc.

Solar drying can be considered as an elaboration of sun drying and is an efficient system of utilizing solar energy (Bala, 1997a & 1998, Zaman and Bala, 1989 and Muhlbauer, 1986). Several designs are available and these are (i) cabinet type solar drier suitable for drying fruits and vegetables (Sharma et.al, 1995), (ii) indirect natural convection solar drier for paddy drying (Oosthuizen, 1995) and mixed mode AIT drier for drying paddy(Excell, 1978).

The present study aims to design and test a forced convection solar dryer provided with auxiliary electric heater to provide and maintain the air drying temperature during drying high moisture date (Hayani var.) under different levels of drying air temperature , air velocity and date treatments. Two different drying models (simple exponential and Page) were examined for describing the drying behaviour of date. Thermal efficiency and final quality of the dried date were also determined.

MATERIALS AND METHODS

Materials:

The experimental work was executed at the department of Agricultural Engineering, Mansoura University during the period of September, October and November 2007 in Mansoura, Egypt

Fresh, ripe hand harvested samples of date palm (Hayani) were used in this study. It was obtained from a local date producing farm in Damitta governorate. The initial moisture content of the freshly harvested date was ranged from 97.36% to 118.45 % dry basis and the total sugar content ranged from 44.58 % to 65.14 % dry basis.

Preparation of Samples:-

The date sample was divided into three sub samples as follows :

1- The first sample was unpeeled only and coded as (T_1).

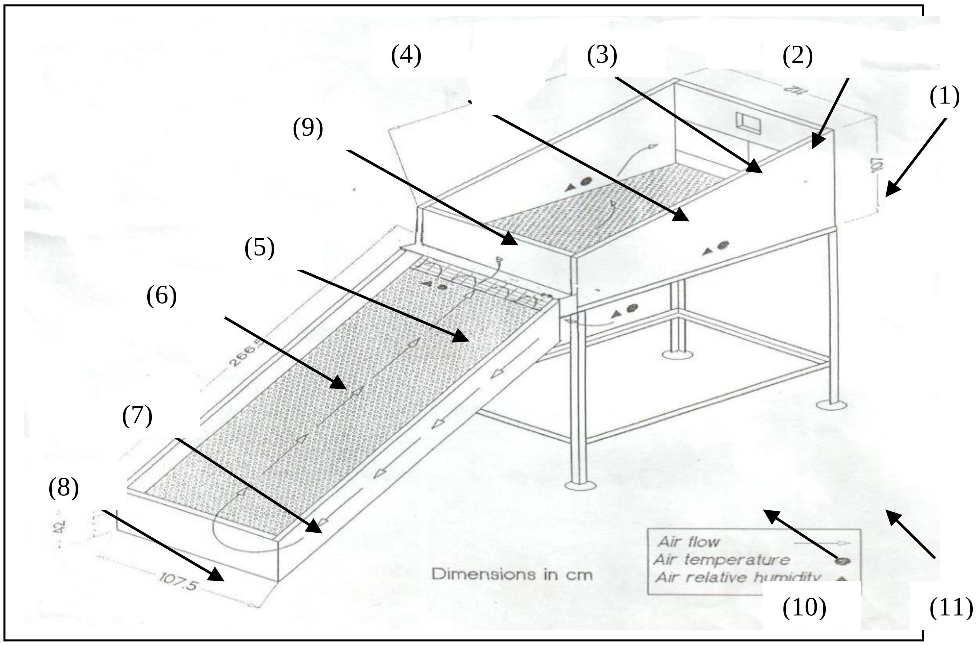
2- The second sample was blanched by dipping in a solution containing 1.5% Potassium metabisulphite as recommended by Inayatullah et.al (1989) and coded as (T_2) .

3-The third sample was peeled date without any treatment and coded as (T_3).

Equipment

The solar dryer:-

A forced convection solar dryer shown in Fig (1) was constructed at a local workshop. The drying box of the dryer consists of four double sides of plywood that filled with an insulation (foam) of 5 cm thick. The gross dimensions of the box were 177 ,122 , 57.50 and 107 cm for length, width , front height and back height respectively. The base of the drying box was made of a perforated stainless steel sheet to keep the dates from falling down and permit the air to move through it . A plenum chamber was formed under the drying box to allow air flow through the drying bed. The main solar collector was fixed at the front side of the dryer. The collector consists of a wooden frame of 266.5 cm long ,107.5 cm wide and 42 cm high surface area covered by 150µ thick plastic sheet. A corrugated black painted aluminium sheet was employed as an absorber plate and fixed at the center of the collector frame between the upper and bottom surfaces to increase the efficiency of energy collection and to allow the drying air to contact with both sides of the absorber plate. The slope of the collector was adjusted at 41º with the horizontal level. While , the top surface of the dryer was covered by a plastic sheet of similar thickness . The dryer was carried out on four ground wheels of 0.75 cm diameter. An axial flow type fan was used for air suction through the drying bed at the required air flow rate .The components of the dryer and the direction of air flow are presented in Fig. (1). To maintain the drying air temperature constant at the required levels during the experimental work , 8 kW auxiliary electric heater with digital thermostat was also functioned .



1	The drying box	2	Air suction fan	3	Charging and discharging door
4	Drying bed	5	Auxiliary heaters	6	The solar collector
7	Corrugated sheet of the solar collector	8	Transparent cover	9	Transparent cover
10	Dryer stands	11	Ground caster wheels		

Fig.(1) : Schematic diagram of the developed solar dryer.

Experimental Measurements:

Date moisture content:

The moisture content of date was determined by drying 10 g(in duplicate) samples of dates in an oven at 70^{O}C until reached constant weight , according to (AOAC 1990).

Air velocity and relative humidity:

The velocity of drying air was measured using a digital air velocity instrument connected with a velocity probe 0.1 to 10 m/sec and accuracy of ± 0.1 m/s.

Air temperature :

A digital thermometer of 12 points -40 to 104.4 ºC and accuracy of ±0.2 ºC was used for measuring the air and date bulk temperatures at different points inside and outside the dryer. The air relative humidity was also measured at the same points using a humidity meter mode (H.D-205).

Solar radiation.

The solar radiation data were collected from weather station installed on the roof of Agriculture Engineering Department, Mansoura University.

The overall thermal efficiency of the solar dryer

The ratio of useful heat (Q_u) to the available heat (Q_i) is defined as the efficiency of solar drying system (η_{th}). It can be calculated as follows (Abdelatif, 1989):

$$\eta_{th} = (Q_U / Q_I) \times 100 \quad ,\% \quad \ldots\ldots(6)$$

$$Q_U = m_r\, h_{fg}/3600 \quad , kW \quad \ldots\ldots(7)$$

$$Q_I = A_C\, R + Q_E \quad , kW \quad \ldots\ldots(8)$$

Where:

m_r = mass of moisture removed , kg/hr.

h_{fg} = Latent heat of vaporization of water , kJ/kg.

A_c = area of collector , m^2.

R = solar radiation flux incident , W/m^2.

Q_E = electric energy of heaters ,W.

The latent heat of vaporization of water was taken from steam table as 2406.8, 2382.8 , 2358.5 and 2333.8 kJ/kg at drying air temperature of 40 , 50, 60 and 70 °C , respectively .

Total sugar and percentage reduction in sugars:

Total sugar and percentage reduction in sugars were extracted by ethanol 80% and determined according to the method descriped by Somogi (1952).

Experimental procedure:

Before each run, the dryer was adjusted at the required level of drying air temperature and air velocity. After that , the dryer bed was loaded with the date sample which was distributed uniformly in a single layer. Air velocity and relative humidity were measured every hour during the drying process .While the moisture content of date was determined throughout the drying period at different time intervals and different places of the drying bed until the moisture content almost ceased to approach the final moisture content.

Two different drying models (simple exponential and Page) were examined for describing the thin layer drying behaviour of date palm .

The final moisture content (M_f) was used as an approximate value for the dynamic equilibrium moisture content, taking into account that the drying runs were turned off when the reduction in moisture content was almost ceased, as previously mentioned by Matouk *et al*. (2002) and El-Sahrigi *et al.* (2006). The two models are presented as follows:

1-The simple exponential model:

$$MR = \frac{M - M_f}{M_o - M_f} = \exp(-k_s t) \quad \text{............(1)}$$

1- Page model

$$MR = \frac{M - M_f}{M_o - M_f} = \exp(-k_p\ t^u) \quad \text{.......... (2)}$$

Where:

MR : Moisture ratio, dimensionless

M : Average moisture content at time t, (d.b) kg water / kg dry solid.

M_f : Final moisture content. (d.b) kg water / kg dry solid.

t : Time , min

$k_{s,p}$: Drying constants, min $^{-1}$

u : Experimental constant , dimensionless

To calculate the drying constants, the two models were linearized as follows:

1-The simple exponential model**:**

$$LnMR = -k_s t \quad \text{................ ....(3)}$$

2-The Page model:

$$Ln(-LnMR) = Ln(k_p) + u.Ln(t) \text{.............(4)}$$

The drying constant (k_s) of the simple exponential model was obtained by applying linear regression analysis to the values Ln (MR) and the elapsed drying time (t) (Eq. 3). The slope of the best fit straight line represents the drying constant (k_s).

On the other hand the values of the drying constants of Peg's model (k_p and u), were obtained by applying linear regression analysis to the values of Ln [-Ln (MR)] and the corresponding drying time (Eq. 4). The slope of the fitted line represents the constant (u) while the value of the anti log of the intercept represents the constant(k_p) .

RESULTS AND DISCUSSION

Solar radiation:

To study the thermal performance of the solar dryer it was imperative to consider the amount of solar radiation during the drying process .The hourly average solar radiation flux incident on a horizontal surface during the period of September, October and November 2007 in Mansoura, Egypt were 672.13, 469.33 and 315.19 W/m^2 for September, October and November, respectively. 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 at noon, it then decreased gradually until it reached the minimum value at sunset. The observed variation in solar energy available during the drying period affected the dryer effectiveness in heating air and the differences in air temperature and relative humidity between the inside and outside the solar collector.

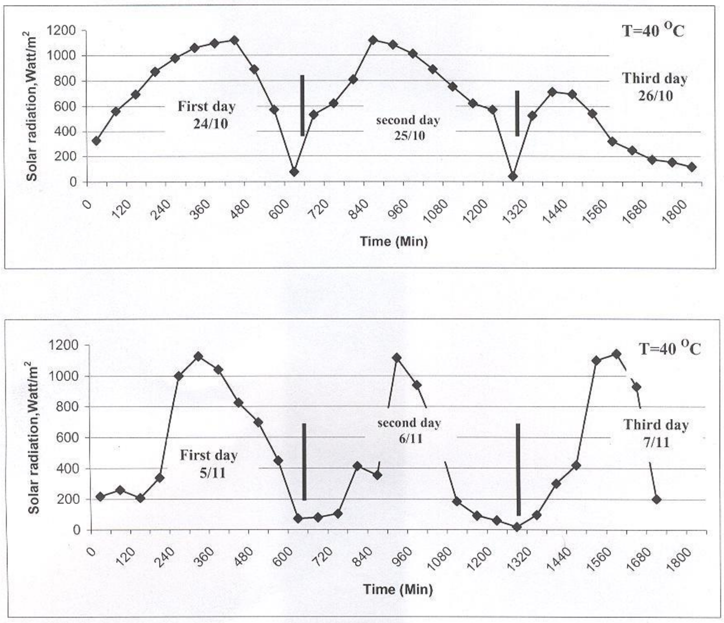


Fig. (2): Solar radiation flux incident versus drying time .

Date Moisture Content:

Figure (3) shows the change in date moisture content as related to drying time for different date treatments. It can be seen that the rate of moisture reduction increased with the increase of air temperature and **air** velocity and it was higher for the unpeeled date (T1) followed by the un-peeled treated date (T2) and the peeled untreated date (T3), respectively .

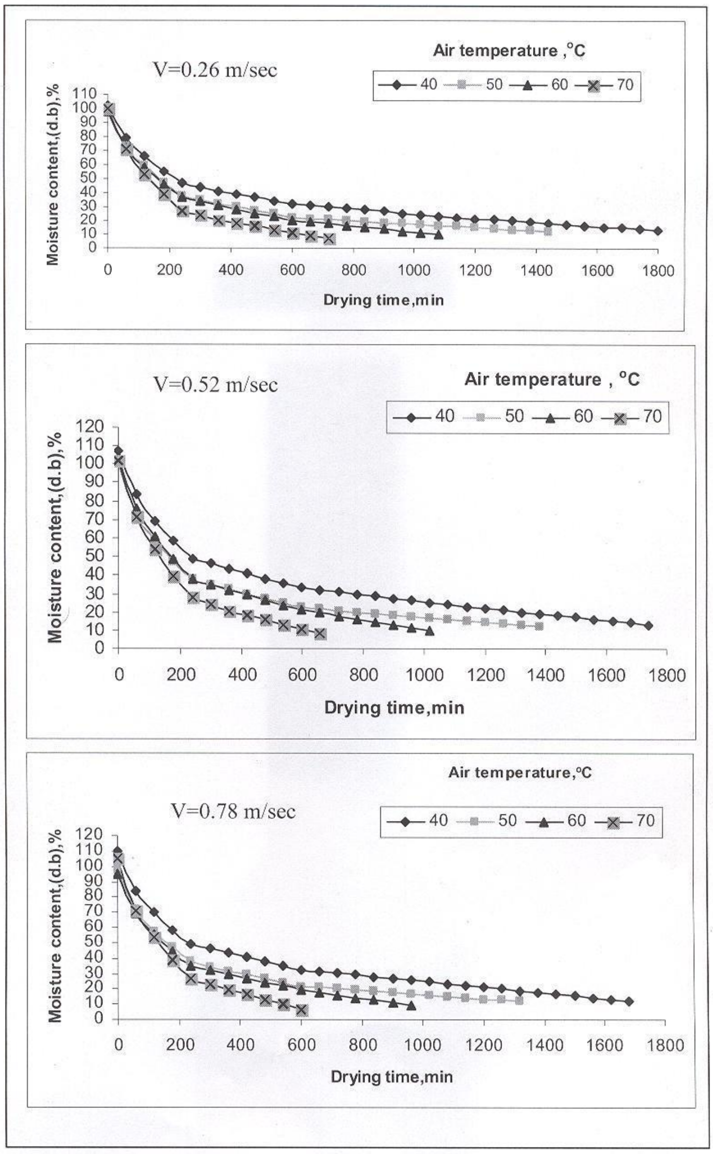


Fig.(3): Change in moisture content of peeled date as related to drying time at different air temperatures and air velocities.

The results of the drying process are summarized and listed in table (1). It indicates that the lowest values of final moisture content occurred with the peeled date treatment followed by the unpeeled treated date and the unpeeled untreated date, respectively.

Table 1: Value of drying constants (k_s ,k_p , u) at different studied drying parameters determined at the average values of final and equilibrium moisture content (M_f and M_e).

Date conditions	V, m/s	T, °C	M_f , %d.b	M_e, %d.b	k_s at m_f , %d.b	k_s at m_e, %d.b	k_p at m_f , %d.b	k_p at m_e, %d.b	u at m_f , %d.b	u at m_e, %d.b
Unpeeled date (T_1)	1	40	13.86	13.16	0.0041	0.0039	0.012	0.0103	0.772	0.7336
		50	12.73	12.24	0.0065	0.0062	0.0232	0.0244	0.8173	0.8003
		60	10.98	10.36	0.0098	0.0088	0.0315	0.034	0.8427	0.8642
		70	9.32	8.47	0.0118	0.0108	0.039459	0.0427	0.9134	0.8866
	1.5	40	13.57	12.66	0.0046	0.0042	0.0154	0.0155	0.7539	0.7238
		50	12.29	11.7	0.0079	0.0075	0.026	0.03	0.7844	0.7702
		60	10.34	10.04	0.01	0.0095	0.035501	0.0394	0.8242	0.8045
		70	8.42	8.23	0.0131	0.0125	0.0433	0.0484	0.8954	0.8694
	2	40	13.12	12.2	0.0049	0.0045	0.0197	0.02	0.7486	0.6764
		50	11.84	11.14	0.0083	0.0076	0.0323	0.0347	0.772	0.7619
		60	10.00	9.57	0.0107	0.0098	0.0413	0.0445	0.803	0.7905
		70	7.89	7.71	0.0135	0.0131	0.046911	0.054	0.8648	0.8476
Unpeeled treated date (T_2)	1	40	13.65	12.53	0.0058	0.0046	0.0122	0.010445	0.76	0.7247
		50	12	11.41	0.0067	0.0063	0.024	0.0247	0.787	0.777
		60	10	9.90	0.0099	0.009	0.0326	0.0353	0.8247	0.82
		70	8.26	7.55	0.0133	0.012	0.040798	0.044	0.9004	0.8709
	1.5	40	12.88	11.77	0.0065	0.0059	0.0155	0.0164	0.735	0.692
		50	11.37	10.67	0.0083	0.0076	0.0293	0.0312	0.7673	0.74
		60	9.45	9.03	0.0106	0.0097	0.0363	0.0405	0.8223	0.7825
		70	8.02	7.11	0.0143	0.0142	0.0449	0.0488	0.8883	0.8534
	2	40	12.34	11.30	0.0069	0.0059	0.02	0.026384	0.704	0.6747
		50	10.83	10	0.0089	0.0077	0.0349	0.039097	0.735	0.7249
		60	9.04	8.25	0.0108	0.0099	0.041382	0.046715	0.7788	0.7675
		70	7.66	6.59	0.015	0.0149	0.050813	0.056	0.8583	0.8422
Peeled date (T_3)	1	40	12.6	12.17	0.0063	0.0051	0.016	0.02	0.7535	0.7227
		50	11.05	10.8	0.0077	0.0069	0.02253	0.0307	0.7897	0.7444
		60	9.63	8.68	0.0101	0.0098	0.0333	0.0405	0.84	0.7865
		70	8.03	6.28	0.0153	0.0129	0.041974	0.0507	0.891	0.8496
	1.5	40	11.85	11.59	0.0069	0.0062	0.022	0.0256	0.7139	0.7012
		50	11.52	10	0.0087	0.0081	0.0295	0.034	0.76	0.7377
		60	9.02	7.98	0.0108	0.01	0.038704	0.0428	0.813	0.7758
		70	6.42	5.87	0.0159	0.015	0.046491	0.054	0.8661	0.8414
	2	40	11.07	10.66	0.0071	0.0068	0.0277	0.0307	0.6937	0.675
		50	9.5	9.15	0.0091	0.0085	0.0352	0.0391	0.727	0.722
		60	8.00	7.4	0.0113	0.0102	0.044073	0.0484	0.7842	0.7744
		70	6.84	5.05	0.0178	0.0158	0.0509	0.0567	0.8566	0.8241

To determine the interaction effect of drying air temperature and air velocity on the final moisture content of different date treatment a multiple regression analysis was used. The nature of dependence can be described by the empirical relation as follows :

$$M_f = a - b\,(V) - c\,(T) \qquad \text{……………. (11)}$$

Where:

M_f = the final moisture content, % (d.b)

a, b, c = constants

T = drying air temperature, °C

V= drying air velocity , m/s

Table (2) reveals the data of the multiple regression analysis. It shows that, the final moisture content (M_f) was strongly affected by the drying air temperature and air velocity for all date treatments.

Table (2): Constants of equations (11) relating the final moisture content with the drying parameters.

Date conditions	Final moisture content (Mf) % (d. b.)				
	a	b	c	(R^2)	SE
T_1	21.93383	-3.23558	-0.14727	0.93	0.548305
T_2	21.45217	-2.44712	-0.1631	0.97	0.349311
T_3	19.90317	-2.73558	-0.15797	0.98	0.269075

Drying Constants k_s , k_p and u :

The two drying models were applied to the data and the drying constants for both models are presented in table (1). In section of the data tabulated in table (1) showed that drying constants of both drying models were affected by the drying parameters (air temperature and air velocity).

A multiple regression analysis was employed to study the effect of both air temperature and air velocity on the drying constants k_s of the simple exponential equation and the drying constants k_p and u of the Page equation The nature of dependence could be described by empirical relations as follow :

$$ks = d + e(T) + f(V) \quad \text{.....……………………(12)}$$

$$kp = g + h(T) + k(V) \quad \text{………………………(13)}$$

$$u = l + m(T) + n(V) \quad \text{……………...………(14)}$$

The constants of equations (12 , 13 and 14) are presented in table (3) . Also Fig . (4) illustrates the drying constants k_s , k_p and u as related to drying air temperature and velocity for the peeled date treatment (T_3) .It must be mentioned that the same trend of relation was also noticed with the other two treatments. In general the drying constants k_s, k_p increased with the increase of drying air temperature and air velocity. While the constant u increased with the drying air temperature and decreased with the increase of air velocity. These results are in agreement with that obtained by Pangavhane, *et al.* (1999) and Azzouz, *et al.* (2002).

Table (3): Constants of equations (8 , 9 and 10) for different date treatments.

Drying constant	Date treatment	d	e	f	R^2	SE
k_s	T1	-0.00164	0.002173	0.0000646	0.90	0.000324
	T2	-0.00261	0.002245	0.0000937	0.97	0.000249
	T3	-0.00289	0.001813	0.000106	0.97	0.000239
k_p	Date treatment	g	h	k	R^2	SE
	T1	0.002091	0.006135	0.000754	0.98	0.000277
	T2	0.000942	0.008618	0.0000896	0.99	0.000286
	T3	0.00033	0.010243	0.000111	0.96	0.000585
u	Date treatment	l	m	n	R^2	SE
	T1	0.731281	-0.19027	0.001684	0.99	0.005068
	T2	0.742831	-0.18673	0.001558	0.99	0.004851
	T3	0.77163	-0.28865	0.001912	0.99	0.003865

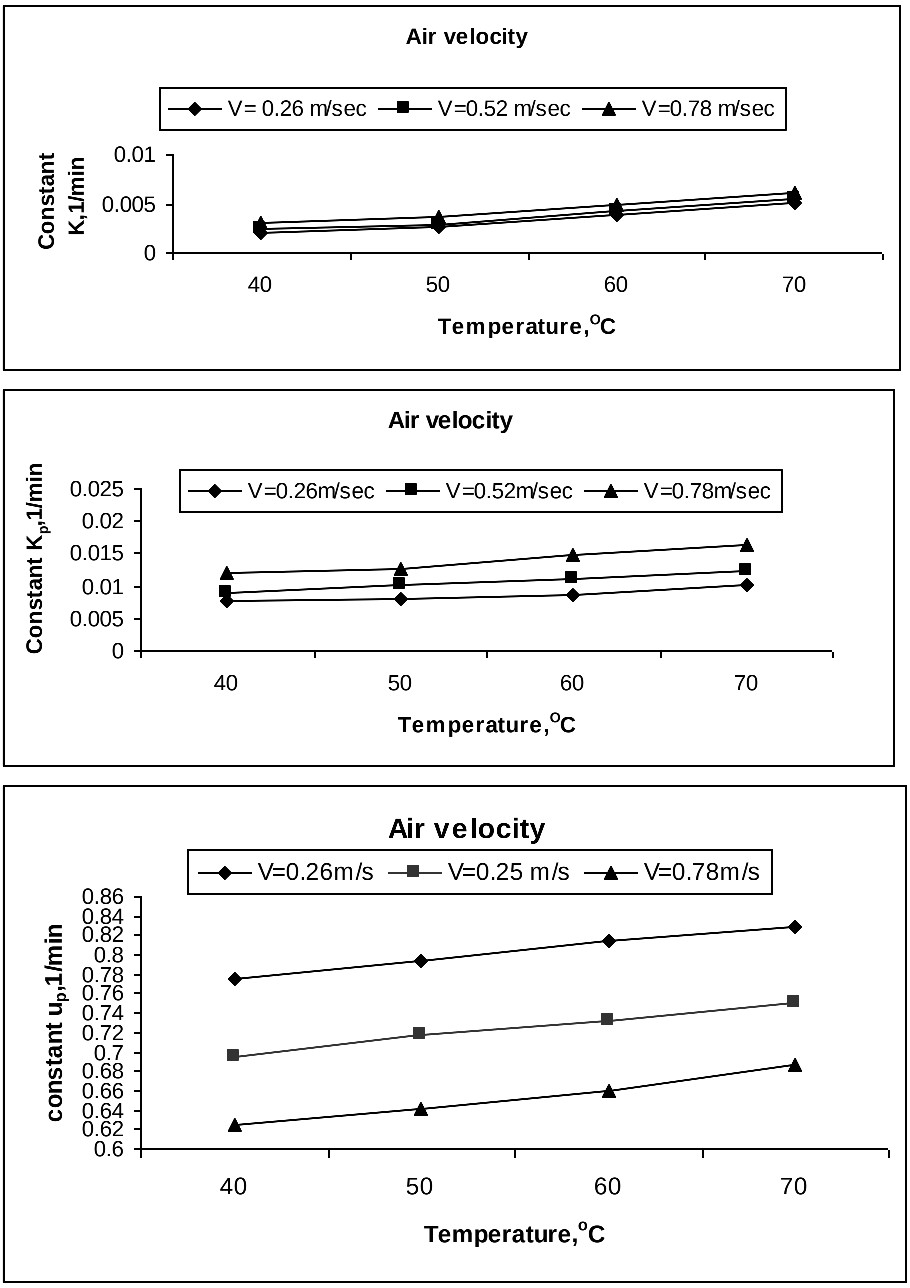


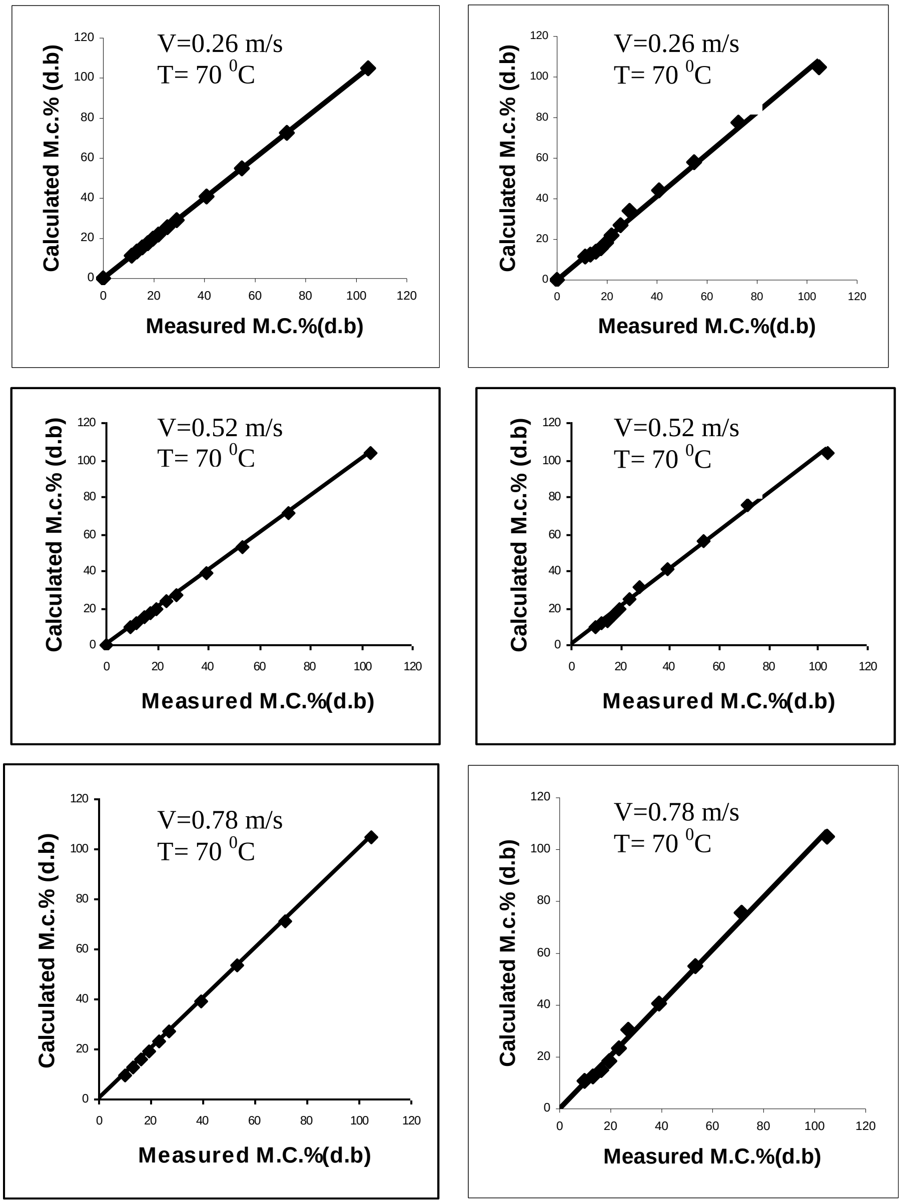
Fig.(4): Drying constants (k_s , k_p and u) as related to drying temperature at different air velocities for the peeled date (T_3) .

Evaluation of the models:

The moisture content of date at any time during the drying process could be estimated using the previous expressions with more accuracy. The consistency of the models and relationship between the coefficients and drying variables was evident with the high values of R^2 and SE shown in Table (3). Fig. (5) indicates the comparison of the predicted and the experimental moisture content (for both model at highest temperature level) for both drying models. Both models (Simple and Page) provided satisfactorily a good conformity between experimental and predicted moisture content, and predicted data generally banded around the straight line, which showed the suitability of the models in describing solar drying behaviour of date. Values of the coefficient of determination and standard error as estimated for all straight lines which are used to compare predicted and experimental moisture contents are shown in table (4). Moreover, the results showed that, both the simple exponential and the Page drying models could satisfactory describe the drying behaviour of date under the tested ranges of experimental treatments. While, the Page's model was more appropriate for describing the drying behaviour of date and predicting the change in date moisture content during the drying process Similar pattern was also noticed for the other runs.

Table (4): Values of regression coefficient (R^2) and standard error (SE) for both forms of simple and Page drying equations.

Date Conditions	Air temperature ,°C	Simple exponential model					
		Air velocity , m/s					
		0.26		0.52		0.78	
		SE	R^2	SE	R^2	SE	R^2
T1	40	6.518	0.95	6.881	0.94	7.485	0.94
	50	6.830	0.95	4.205	0.98	6.239	0.95
	60	5.03	0.96	3.657	0.98	3.893	0.97
	70	3.416	0.99	7.857	0.93	2.499	0.99
T2	40	8.163	0.94	8.014	0.94	3.814	0.98
	50	2.702	0.99	4.013	0.98	5.908	0.96
	60	4.09	0.98	3.968	0.98	8.078	0.91
	70	4.64	0.96	6.801	0.94	2.535	0.99
T3	40	6.23	0.96	7.510	0.94	8.25	0.94
	50	2.67	0.99	3.885	0.98	5.9176	0.95
	60	4.67	0.97	3.689	0.98	4.120	0.98
	70	3.45	0.99	6.934	0.94	8.011	0.92
Date conditions	Air temperature ,°C	Page model					
		Air velocity , m/s					
		0.26		0.52		0.78	
		SE	R^2	SE	R^2	SE	R^2
T1	40	0.0102152	0.99	1.9E-06	1	1.98E-06	1
	50	3.42E-07	1	1.527E-08	1	1.95E-07	1
	60	7.83E-08	1	1.66E-11	1	7.7E-12	1
	70	1.612E-09	1	8.025E-14	1	5.88E-10	1
T2	40	0.053749	0.99	2.11E-06	1	1.45E-08	1
	50	1.27E-07	1	1.9E-08	1	1.84E-07	1
	60	2.1E-09	1	1.55E-11	1	0.0255	0.99
	70	1.67E-09	1	2.37E-15	1	1.23E-10	1
T3	40	9.83E-07	1	1.99E-06	1	2.18E-06	1
	50	6.31E-10	1	1.63E-08	1	1.85E-07	1
	60	1.69E-08	1	1.55E-11	1	1.13E-08	1
	70	1.629E-09	1	2.368E-15	1	1.27E-11	1



(a) Simple model **(b) Page's model**

Fig. (5): Measured and calculated values of moisture content for the peeled date treatment for both models at the highest air temperature.

Total and reducing Sugars:

Total and reducing Sugars decreased with the decrease of the drying air temperature and air velocity. As shown in table (5) at the minimum drying air temperature of 40 ^{0}C and air velocity of 0.26 m/sec, the average total sugars for (T_1,T_2 and T_3) was 49.65,49.85 and 49.96 % (d.b) and the average reducing in sugar was 40.33,40.55 and 40.61 % (d.b) respectively . While at the maximum drying air temperature of 70 ^{0}C and air velocity of 0.78 m/sec the total sugar was 56.49, 56.75 and 56.93 % (d.b) and the average reduction sugar was 44.76, 44.52 and 44.66 % (d.b), respectively . This observation may be attributed to the liberation of sugars from soluble tannins and other compounds such as hemicelluloses as reported by Kamal (1968). Also the long time of heating led to decrease the reducing sugars during the drying process due to the browning reaction as mentioned by (Reynolds, 1965).

Table (5): Total and reducing soluble sugars % (d.b) of the dried date.

Air velocity m/sec	Temperature,^{0}C	Reducing sugars,%(d.b)			Total soluble sugars,% (d.b)		
		T_1	T_2	T_3	T_1	T_2	T_3
0.26	40	40.33	40.55	40.61	49.65	49.85	49.96
	50	41.44	41.66	41.72	51.48	51.68	51.79
	60	42.59	43.1	42.97	53.16	53.57	53.75
	70	43.65	43.86	43.95	54.98	55.19	55.28
0.52	40	40.75	41.02	40.88	50.19	50.38	50.57
	50	41.66	41.88	42.03	51.68	51.95	52.2
	60	42.83	42.77	43.35	53.88	54.09	54.71
	70	44.26	44.11	44.35	55.68	55.93	56.17
0.78	40	41.05	41.12	41.27	50.85	50.92	51.29
	50	42.41	42.33	42.19	52.91	52.63	52.79
	60	43.49	43.41	43.86	54.42	54.59	55.19
	70	44.76	44.52	44.66	56.49	56.75	56.93

Thermal efficiency of the solar collector and the dryer :

Table (6) shows the overall thermal efficiency of the solar dryer with the auxiliary electric heater for the drying process. The overall thermal efficiency of the dryer ranged from 29.29% to 36.87% .It indicates that the solar collector provided 31.03% , 28.80% , 21% and 11.19 % of the total heat energy consumed in air drying heating for 40,50,60 and 70 ^{O}C air drying temperature,respectively. The total heat energy provided and consumed varied from one treatment to another due to the variation in the distribution of solar energy available and energy required in drying process. The main parameters affecting proportions of heat energy consumed in the form of electrical and solar energy were; solar collector surface area,ambient air temperature, solar energy available and drying air temperature required for drying process.

T.6

Conclusions

1- Both of the examined models could satisfactorily describe the change in date moisture content during the drying process. While the, Page's model could predict the change in moisture content of date more adequately than the simple model.

2- Drying constants (k_s and k_p) increased with the increase of drying air temperature and air velocity. While the constant (u) increased with the drying air temperature and decreased with air velocity.

3- The solar collector could provided 10.87 to 35.03 % of total the required energy by energy consumed. The overall thermal efficiency of the solar dryer ranged from 19.19 % to 53.53 % .

4- Total and reducing sugars percentages decreased with the decrease of drying air temperature and air velocity and it ranged from 40.33 to 44.66 % d.b. for the reducing sugar and from 49.65 to 56.93 % d.b. for the total soluable sugar.

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تجفيف البلح الحياني في طبقات رقيقه بإستخدام مجفف شمسي

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أجريت هذه الدراسة لإختبار وتقييم مجفف ميكانيكي لتجفيف البلح بإستخدام غاز البوتوجاز كمصدر للطاقة الحرارية. وذلك بإجراء مجموعة من التجارب المعملية لدراسة تأثير مستويات مختلفة من درجة حرارة هواء التجفيف(40, 50 , 60, 70 °م) وسرعة هواء (0.26, 0.52, 0.78) م/ث.
تم أيضا إختبار نموذجين رياضيين لوصف منحني التجفيف للبلح في طبقات رقيقه شملت (المعادلة البسيطة , معادلة Page).

وقد أظهرت النتائج المتحصل عليها مايلي:

1. وصف كلا النموذجين الرياضيين التغير في المحتوي الرطوبي للبلح بشكل مرضي, بينما أعطت , معادلة Page نتائج أكثر دقة للتغير في المحتوي الرطوبي للبلح أثناء عملية التجفيف مقارنة بالمعادلة البسيطة.
2. زادت قيم كل من ثوابت التجفيف (k_s and k_p) بزيادة كلا من درجة حرارة وسرعة هواء التجفيف بينما زادت قيم ثابت التجفيف (u) بزيادة درجة حرارة هواء التجفيف وانخفضت بزيادة سرعة هواء التجفيف.
3. إنخفضت السكريات الكلية والمختزلة بإنخفاض درجة حرارة وسرعة هواء التجفيف حيث تراوحت السكريات المختزلة بين 44.66 – 40.33 % على الأساس الجاف بينما تراوحت السكريات الكلية بين 56.93 – 49.65 % على الأساس الجاف.

4- تراوحت كمية الطاقة المتوفرة من المجمع الشمسي بين(10.87 الي 35.03 %) من الطاقة الكلية المستهلكة , بينما تراوحت الكفاءة الكلية للمجفف الشمسي بين (19.19 الي 53.53 %).

قام بتحكيم البحث

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Table (6): Thermal efficiency of the solar dryer at different drying air temperature and velocity.

Draying air temp., °C	Air velocity, m/sec	Date	Ailable solar radiation, kwh	T_{ai} °C	T_{ao} °C	T_{aoh} °C	Mass of moisture removed, kg	Latent heat of water, kJ/g	Required heating for evaborative, kJ	Average of electric power of auxiliry heaters, kWh	Total heat energy consumed, kW	Daily average of thermal efficiency,%	Overall thermal fficiency for each experiment, %	Daily energy propration of solar collector,%	Average energy saving of solar collector%	Average energy saving of solar collector%
	0.26	24/10/2007	1.0868	26.36	36.33	38.51	2.47	2416.222536	5968.069663	2.01	3.0968	53.53258617		35.09429088		
		25/10/2007	1.055875	25.31	37.74	39	0.805	2416.222536	1945.059141	1.9875	3.043375	17.75312625	29.29	34.69421284	35.03	
		26/10/2007	1.085325	24.88	38.35	39.5	0.76	2416.222536	1836.329127	1.9875	3.072825	16.60008052		35.32010446		
	0.52	29/10/2007	0.92945	25.3	36.4	39.35	2.58	2415.266659	6242.603028	2.15325	3.0827	56.25122123		30.1505174		
40		30/10/2007	0.883825	25.84	35.79	39	1.12	2415.266659	2719.89173	2.15325	3.037075	24.87674755	33.60	29.10119111	29.58	31.03
		31/10/2007	0.901475	25.73	38.08	39.4	0.89	2415.266659	2165.846373	2.15325	3.054725	19.6948659		29.51083976		
	0.78	05/11/2007	1.035477	27.06	38.91	40.01	2.77	2416.092267	6713.436421	2.303	3.338477	55.85910732		31.01644852		
		06/11/2007	0.900531	25.73	36.68	39.05	1.35	2416.092267	3276.350834	2.303	3.203531	28.40919766	34.04	28.11057549	28.48	
		07/11/2007	0.8235	26.03	33.81	40.3	0.83	2416.092267	2010.943033	2.303	3.1265	17.86647327		26.33935711		
	0.26	21/09/2007	1.350459	28.36	40.68	48.76	3.08	2391.407845	7377.286911	3.078	4.428459	46.27447977	34.77	30.49500966	30.27	
		22/09/2007	1.323	27.31	39.31	49.67	1.54	2391.407845	3688.952891	3.078	4.401	23.28355229		30.06134969		
50	0.52	25/09/2007	1.3095	26.88	38.1	47.65	2.82	2391.318133	6758.448902	3.22575	4.53525	41.39456297	30.80	28.87382173	28.76	28.8
		26/09/2007	1.296	26.5	36.47	48.67	1.37	2391.318133	3291.065553	3.22575	4.52175	20.21750154		28.66146956		
	0.78	29/09/2007	1.269	26	38.43	47.5	3.78	2395.387414	9070.383807	3.3495	4.6185	54.55344933	36.87	27.47645339	27.37	
		30/09/2007	1.255986	25.34	38.81	49.3	1.32	2395.387414	3182.022817	3.3495	4.605486	19.19222481		27.27151923		
	0.26	03/10/2007	1.140375	29.08	40.18	57.62	2.77	2368.888968	6568.422471	3.676725	4.8171	37.87676813	29.64	23.67347574	22.91	
		04/10/2007	1.046775	28.16	38.11	58.9	1.53	2368.888968	3641.488981	3.676725	4.7235	21.41472885		22.16100349		
60	0.52	07/10/2007	0.9385	27.17	39.52	57.71	3.02	2367.179558	7151.519426	3.7376625	4.6761625	42.48212447	33.262	20.06987567	20.51	21
		08/10/2007	0.99065	27.11	38.96	59.6	1.72	2367.179558	4092.583475	3.7376625	4.7283125	24.04301203		20.95144938		
	0.78	11/10/2007	0.8302	26.03	36.98	57.91	3.21	2371.824441	7615.085149	3.7674	4.5976	46.0088183	36.38	18.05724726	19.58	
		12/10/2007	1.008	27.06	34.84	58.38	1.93	2371.824441	4599.810722	3.7674	4.7754	26.75640157		21.10817942		
	0.26	15/10/2007	1.12165	26.66	38.98	67.65	4.41	2348.418213	10356.52432	8.4	9.52165	30.21338015	30.21	11.77999611	11.78	
70	0.52	16/10/2007	1.06285	25.7	37.7	67.71	4.98	2347.068178	11688.39953	8.712	9.77485	33.21562629	33.21	10.87331263	10.87	11.19
	0.78	17/10/2007	1.094775	26.1	37.32	67.88	5.33	2357.37548	12564.81131	8.928	10.022775	34.82294438	34.82	10.92287316	10.92	