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ENGINEERING STUDIES ON TOMATO DRYING

A.M.Kshta * Mona M. A. Hassan ** Aml -El-Zanaty ***

ABSTRACT

The present paper presents the design, construction and performance evaluation of a mixed-mode solar dryer for drying tomato. In the dryer, the heated air from a separate solar collector is passed through tomato slices, and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls and roof. The results obtained during the test period revealed that the reduction in tomatoes moisture content was varied with the increase of slices thickness and drying air velocity, while it was decreased with the increase of slices thickness. Drying rate decreases continuously with diminishing moisture content and was much lower with 0.5 m/s air velocity and 3 mm thickness. The maximum temperature recorded inside the dryer chamber was 56° C when the corresponding ambient temperature and relative humidity were 34° C and 30.8%, respectively with 3 mm thickness and 0.5 m/s air velocity.

The drying rate constants 'k_s', 'k_p' and u values were decreased with increasing the slice thickness and air velocity. Both the simple exponential and Page drying models could satisfactory describe the drying behavior of tomato under the tested ranges of experimental treatments. The Page's model was found to be more appropriate for describing the drying behavior of tomato and calculating the change in tomato moisture content during the drying process.

Keywords: solar energy, solar dryer, mixed-mode dryer, tomato, performance evaluation.

INTRODUCTION

Drying is one of the important food preservation methods, which has been extensively researched in the past few years. Hence, this field takes considerable importance and there is also a need to improve and develop this process to the highest extent possible.

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Since, the vegetable commodities are highly heat sensitive, the drying methods have to be designed to suit this criterion. Dried tomato products in the form of slices, halves, quarters and powder are becoming popular for adding as a component in pizza, soup and preparation of other food items. Drying itself is an energy intensive operation and hence, the renewable form of energy has been selected to make the drying operation sustainable. Therefore, experiments were performed to develop and evaluate the solar drying methods to improve the product quality.

Egypt is one of countries which have solar energy in abundance. It lies within the tropical and subtropical region. It has a value of about 5 to 8 $kW.h/m^2.day$ and that sun-shine duration per year extends to about 4100 hours ***(Al-Awady et al.1993). Wang (2002)*** concluded that Page model was found to give the best results in describing single-layer far-infrared radiation drying of onion. Tomatoes, as other vegetables, can be dried using various methods. In any tomato drying technique, the required time for drying the product depends on many parameters such as tomato variety, the soluble solids content of the fresh product, the air humidity, the size of the tomato segments, the air temperature and velocity and the efficiency of the drying system. Traditional sun-drying has the advantages of simplicity and the small capital investment, but it requires long drying times that may have adverse consequences to the product quality. The final product may be contaminated from dust and insects or suffer from enzyme and microbial activities. It is obvious that the ideal conditions for drying tomatoes are mild temperatures between 45 and 55 °C, which enable the dried product to retain its nutrients (including vitamins and lycopene, the nutrient responsible for the deep-red color of tomatoes) and flavors ***(Andritsos et al., 2003). Madamba et al., (2003)*** reported that the drying air temperature and slab thickness significantly affected the average drying rate of mango slices. ***(Simal et al. 2005)*** used three different mathematical models to simulate the drying kinetics of kiwi fruits. Two empirical models (the exponential and the Page models) solved by the separation of variables method. They reported that, air temperature affected the drying curves by decreasing the drying time of samples, and the Page model shows the best simulation of the drying curves of kiwi, whereas the exponential model showed less satisfactory simulation. Drying crops by solar energy is a great economic importance allover the world, especially in sub-Sahara Africa where most of the crops and grain harvest are lost to fungal and microbial attacks. These wastages could be easily prevented by proper drying which enhances storage of crops over a long period of time ***(Ezekoyi and Enebe; 2006).*** In the mixed-mode solar dryer, it was observed that the drying rate increased due to increase in temperature between 10:00 a.m. and 14:00 p.m. but decreased thereafter, which shows the earlier and faster removal of moisture from the dried item. The dryer was able to remove 85.4% of moisture, dry basis, from 6 kg of yam chips in one day of 10 hours drying time, which is about 0.6 kg/h drying rate. The collector efficiency of the mixed-mode solar dryer during the test period was found to be 57.5% ***(Bukola and Olalusi;2008). Emara (2010)*** found that at the minimum air velocity of 0.4 m/s, the solar collector of the dryer could increase the average air temperature inside the dryers having sugar beet tops of 3, 6 and 9 cm lengths by about 11.05, 11.63 and 11.25 °C and decreased the air relative humidity by about 24.84, 26.09 and 24.98%, respectively. While at the maximum air velocity of 1.2 m/s, the air temperature was increased by about 10.79, 11.99 and 11.94 °C and the air relative humidity decreased by about 24.17, 26.47 and 26.81 %, respectively. ***(Ofor and Ibeawuchi. 2010)*** mentioned that dried tomatoes are a common sight in most markets in South-eastern Nigeria. These dried products are usually packaged in jute sacks placed inside polyethylene bags. Data collected during a survey of the quality of dried tomatoes marketed in urban markets in Owerri (South-eastern Nigeria), revealed that the dried product usually sourced from farms in Northern Nigeria, had mean moisture content ranging from 17.51% - 27.20%, depending on the location. ***El-desoky (2011)*** stated that both the final moisture content (M_f) and the equilibrium moisture content (M_e) decreased with the increase of drying air temperature and air velocity for different date conditions. However, the final moisture content (M_f) was more affected by the drying air temperature and velocity in comparison with the equilibrium moisture content (M_e).

The specific objectives are:

1. To fabricate and test a mixed mode solar dryer (a mixed-mode solar dryer in which the material is dried simultaneously by both direct radiation through the transparent walls and roof of the cabinet and by the heated air from the solar collector) to evaluate the solar dryer performance using tomato slices.
2. Studying the effect of some engineering parameters on the performance of the dryer.
3. To examine two different drying models (simple exponential and Page model's) for describing the drying behavior and predicting the changes in tomato moisture content.

MATERIALS AND METHODS

The solar dryer (Fig.1) was constructed at local workshop in Tanta city (Longitude =31° 00° and latitude =30° 47°). The main experiments were conduction during 2011 season. The dryer consists of three main parts namely; solar collector, drying chamber and air suction fan. The specifications of the solar dryer can be presented as follow:

The solar collector :

The solar collector was attached to the front side of the dryer. The collector consists of a wooden frame of 184 x 92 x 15 cm, a corrugated black painted iron sheet 0.5 mm thickness to increase the efficiency of energy collection. The slope of the collector was adjusted to 30° with the horizontal level, while the top surface of the solar collector was covered by a glass sheet of 5 mm thickness. The front side was made from a perforated stainless steel sheet as a window for air inlet. The window's dimensions are 92 × 15 cm at the north side. The collector was oriented North-South.

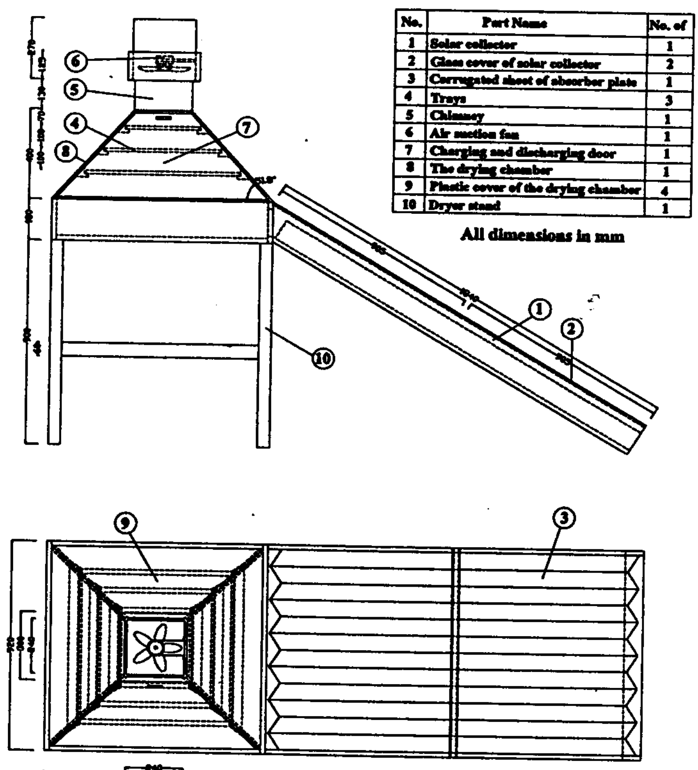
The drying chamber:

The drying chamber was constructed as the pyramid shape. The gross dimensions of the chamber were 92 x 92 cm. The base of the drying chamber consists of: 1- frame made from plywood which vehicles with angles such as Giza pyramids angles, 2- An axial type suction fan with five blades (220-230 v, 50-60 Hz, 16 w, 0.5 A and 1300-1550 r.p.m) and a duct for air suction were settled at the top of the dryer. The dimensions of this air channel were 25x25 cm and covered by perforated stainless steel. 3- The four trays consist of a fabricated from wood bars and made from perforated stainless steel sheet that net surface area were (0.65, 0.435, 0.25, and 0.105 m^2) respectively (arranged from bottom to top). The distance between two consecutive trays was 7.5 cm and the trays were arranged one above the other. 4- The dryer covered by plastic sheet. 5- Four legs 90 cm length were connected at the corners of the bottom of the dryer to elevate the body of the dryer from the ground.

Experimental Test Procedure:

Performance of the drying process was tested under the following parameters:

1. Two different air velocities (0.5, and 2 m/s)
2. Two different thicknesses of tomato slice (3 and 5 mm).



No.	Part Name	No. of
1	Solar collector	1
2	Glass cover of solar collector	2
3	Corrugated sheet of absorber plate	1
4	Trays	3
5	Chimney	1
6	Air suction fan	1
7	Charging and discharging door	1
8	The drying chamber	1
9	Plastic cover of the drying chamber	4
10	Dryer stand	1

Figure(1):Schematic diagram of the solar dryer.

Experimental steps

1- The dryer preparation:

Before each run, the dryer was adjusted for the required level of air velocity.

2- The dryer bed was loaded with the tomatoes slices which were distributed uniformly in a single layer.

3- Air temperature, velocity, relative humidity and moisture content were recorded every 5 min during the first hour, then every 10 min during the second hour, then every 15 min during the third hour, then every 20 min during the forth hour, then every 30 min during the fifth hour and finally every 1 hour up to the end of the run during the drying process at different points. Moisture content was measured before the drying process and throughout the drying period at different places of the drying bed by taking slice of tomato sample in four replicates and using the electric oven at 70 ^{O}C for 24 h. The drying process was kept running until the sunset.

Experimental Measurement and Measuring Equipment:

1- Weight of fruits:

Weight of fruits was measured using an electrical digital balance model (TE 214S) with maximum capacity of 210 g and (±0.1 mg) accuracy.

2- Air temperature, air velocity and relative humidity:

Tri-SENSE model No. 37000-00 measures temperature, humidity and air velocity, made in USA. The range for air velocity is (0 to 25 m/s) with accuracy of (±0.2 m/s) and the range for temperature form (-29 to 70 °C) with accuracy of (±1.5 °C). Hydro-Thermo-Anemometer measures temperature, humidity and air velocity, made in Japan. The range for air velocity is (0.4 to 25 m/s) with accuracy of (±0.2 m/s), The range for temperature form (0 to 50 °C) with accuracy of (±0.8 °C) and the range for relative humidity form (10 to 70 RH) with accuracy of (±3 RH) and form (70 to 95 RH) with accuracy of (±4 RH).

3- Measurement of the hourly total solar radiation (I_T):

The solar radiation data were collected from the weather station "Watchdog" model 900 ET. The Weather station measures wind speed (0-175 mph) ± 5%, wind direction (2° increments) ± 7°, temperature (-30° : 100° C), relative humidity (20-100%) ± 3%, rainfall (0.01-0.25 cm) ± 2% and solar radiation (1- 1250 W/m^2).

4- Estimation of the moisture ratio (*MR*) and drying rate:

The moisture ratio (*MR*) and drying rate were calculated by using the following equations:

$$MR = \frac{M_t - M_e}{M_i - M_e}, \text{ decimal}$$

$$M_e = (M_i + M_f) - (Mm)^2 / (Mi + M_f) - 2(Mm) \quad \text{(O,Callaghan and Nellist,1971)}$$

$$Drying\ rate = \frac{M_{t-dt} - M_t}{dt}, \text{ kg water/min}$$

Where: M_i, M_f are initial and final moisture contents (db), *Mm* is moisture content at half time (db), M_e is material moisture content in equilibrium with the drying air (db), M_{t-dt} and M_t are the moisture contents at t-dt and t times, respectively (db), and dt is the drying time period (min.).

- Thin layer Drying Equations:

- The simple exponential equation (*Hukill, 1947*):

$$MR = \frac{M - M_e}{M_o - M_e} = exp(-kt)$$

Where: MR: Moisture ratio (db), dimensionless; M: Material moisture content, (db); t: Time, (h); and k: the drying rate constant, (min^{-1}).

The simple exponential model has been applied to fit the drying data of the product after converting its form to the logarithmic form relating the moisture ratio (MR) of the tested sample with the elapsed drying time "t" as follows:

$$Ln\ MR = (-kt)$$

2- Page's model *(Page, 1949):*

$$MR = \frac{M - M_e}{M_0 - M_e} = exp(-kt^n)$$

The Page's model has been applied also to fit the drying data after converting its form to:

$$Ln(-Ln(MR)) = Ln(K) + u.Ln(t)$$

u: the drying rate constant, (min^{-1}).

RESULTS AND DISCUSSION

The discussion covers the obtained results under the following headings:

Influence of drying air characteristics on the change in tomatoes moisture content and drying rate:

Figures (2, 3, 4 and 5) illustrate the change in tomatoes moisture content as related to drying time at different levels of drying air velocity and slice thickness. As shown in the figures, the reduction in tomatoes moisture content was varied with the drying air velocity and slice thickness. While it was decreased with the increase of air velocity, it is also decreased with the increase of slice thickness.

The changes in moisture ratio with drying time of tomato slices are shown in Figures (6 and 7), as shown in the figure, drying rate decreases continuously with diminishing moisture content and was much lower with 0.5 m/s air velocity and 3 mm thickness so the amount of moisture removed in 0.5 m/s air velocity and 3 mm thickness was relatively smaller. Meanwhile no constant drying rate period was detected for all studied levels of drying air velocity and slice thicknesses. While all the drying process occurred during the falling rate-drying period.

This phenomenon is common for most fruit and vegetable crops, since at the beginning of drying process, the moisture diffusion from the tomato interior toward the surface where it evaporates has been limited. This condition continue until the temperature of the tomatoes reaching the drying air temperature as mentioned by Pangarvhane, et al. (2000); Yaldiz, et al. (2001) and Togral, et al. (2004).

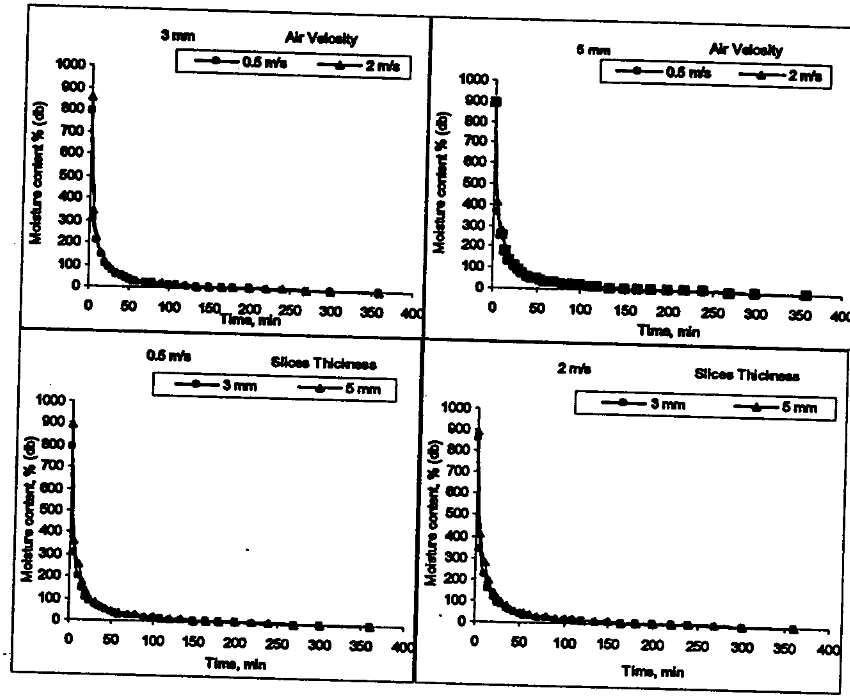


Figure (2,3,4 and 5): Change in tomatoes moisture content as related to drying time at different slice thicknesses and drying air velocities.

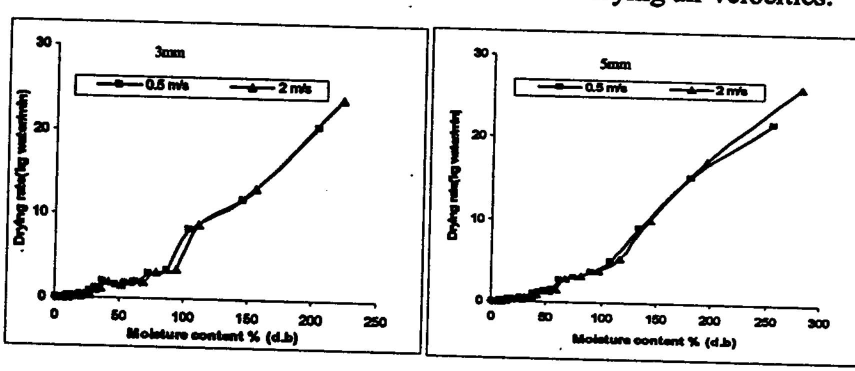


Figure (6 and 7): Change in drying rate as related to tomatoes moisture content at different slice thicknesses and drying air velocities.

Drying Characteristics due to Weather Parameters:
During the experimental period in September 2011, the average daily variations of solar radiation, wind velocity, ambient relative humidity and air temperature were ranged from 312 to 795.6 W/m^2, 4.8 to 12.9 m/s, 49.9% to 64.2 and 27.7 to 34°C, respectively in Tanta, (Figure 8). The air temperature started increasing significantly during 12:00 -14:00 h, whereas the relative humidity reached the lowest value during this period. Generally, the drying temperature, relative humidity and wind velocity varied continuously during the drying period from 10:00 to 18:00 h due to the variation of solar isolation. Figure (9) shows that the maximum temperature recorded inside the dryer chamber was 56°C when the corresponding ambient temperature and relative humidity were 34° C and 30.8%, respectively with 3 mm slice thickness and 0.5 m/s air velocity.

Drying Rate Constant:
The drying rate constants 'k_s', 'k_p' and u were determined for the tomato dried slices. The results are presented in Figures (10, 11, 12, 13, 14, 15, 16 and 17). From the figures, it is observed that the drying rate constants 'k_s', 'k_p' and u values decreased with an increase in slice thickness and air velocity for both the simple exponential and Page drying models. The Page model gave higher coefficient of determination R^2 values (0.9906, 0.9906, 0.9933 and 0.9901) for (air velocity 0.5 m/s and 3 mm slice thickness), (air velocity 2 m/s and 3 mm slice thickness), (air velocity 0.5 m/s and 5 mm thickness) and (air velocity 2 m/s and 3 mm thickness) respectively .The experimental and predicted data using Page model for moisture ratio of dried tomato slices are shown in Figures (14, 15, 16 and 17). There is a good agreement between the experimental moisture ratios and the predicted values. Wang (2002) also concluded that Page model was found to give the best results in describing single-layer far-infrared radiation drying of onion. Figures (7, 8, 9, 10, 11, 12, 13 and 14) shows the relation between measured and calculated moisture content for 3 and 5 mm slice thicknesses and 0.5 and 2 m/s air velocities using simple and Page's equations. In order to compare and evaluate the two examined models for describing the drying behavior and calculating the change in

tomato moisture content, a straight line was fitted by least square method to the values of the observed and the calculated moisture contents.

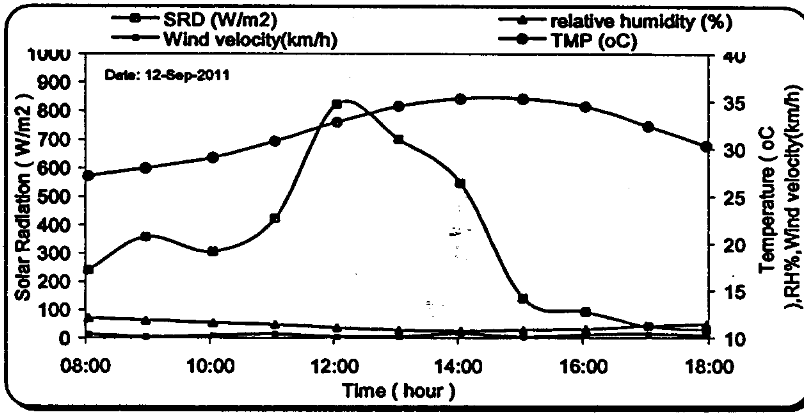


Figure (8) Ambient temperature, relative humidity and wind velocity observed during the drying experiments.

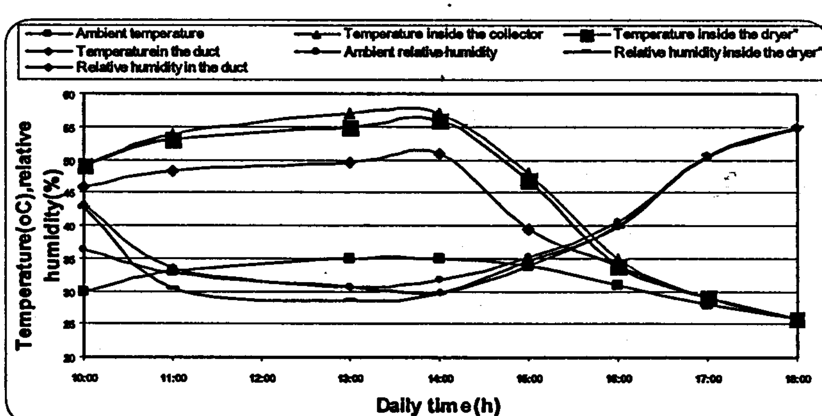
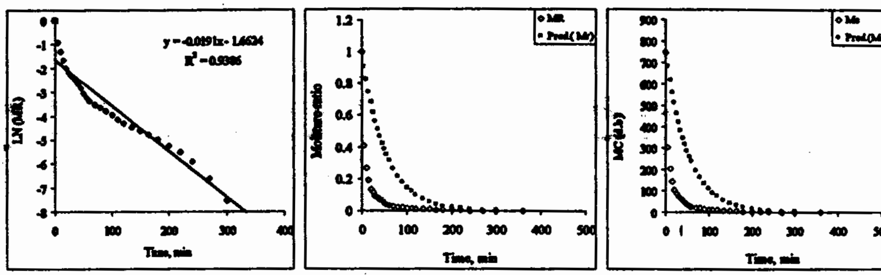
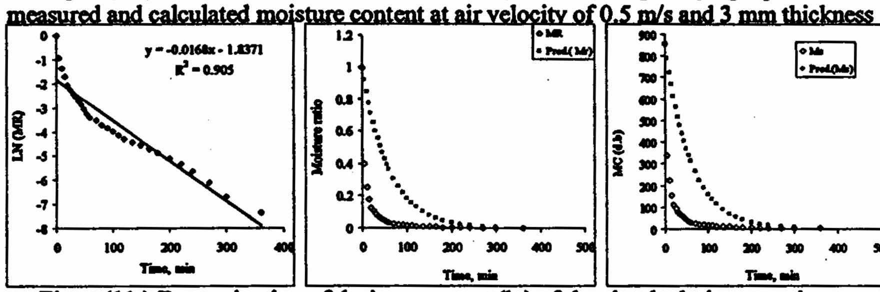


Figure (9): Temperature and relative humidity observed with 3mm thickness and 0.5 m/s air velocity.

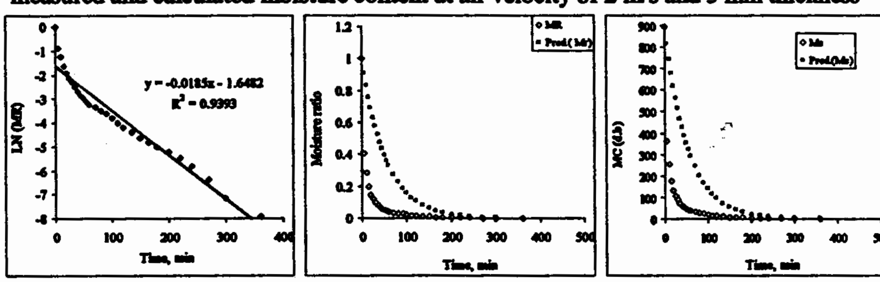
It can be seen that, both the simple exponential and Page drying models could satisfactory describe the drying behavior of tomato under the tested ranges of experimental treatments. While, the Page's model was found to be more appropriate for describing the drying behavior of tomato and calculating the change in tomato moisture content during the drying process.



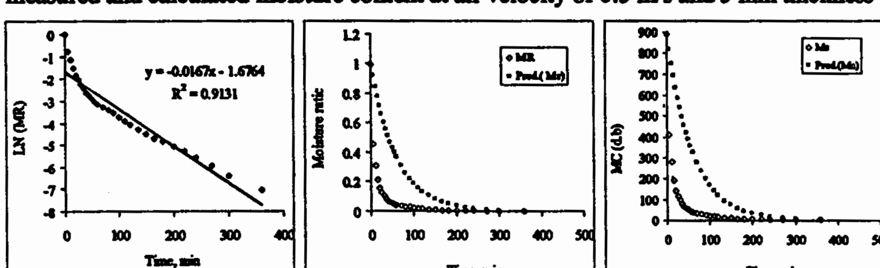
Figure(10):Determination of drying constant (k_s) of the simple drying equation, measured and calculated moisture content at air velocity of 0.5 m/s and 3 mm thickness



Figure(11):Determination of drying constant (k_s) of the simple drying equation, measured and calculated moisture content at air velocity of 2 m/s and 3 mm thickness



Figure(12):Determination of drying constant (k_s) of the simple drying equation, measured and calculated moisture content at air velocity of 0.5 m/s and 5 mm thickness



Figure(13):Determination of drying constant (k_s) of the simple drying equation, measured and calculated moisture content at air velocity of 2 m/s and 5 mm thickness

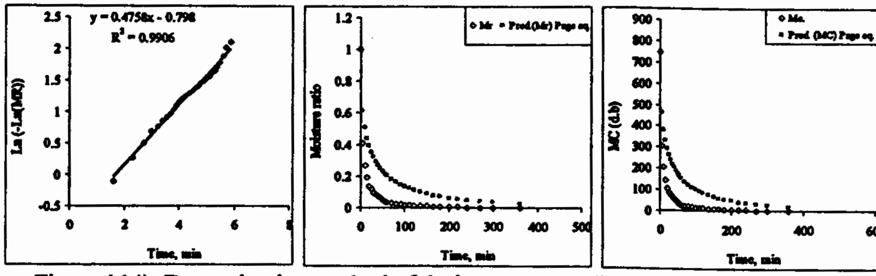


Figure (14): Determination method of drying constants (k_p and u) , measured and calculated moisture content at air velocity of 0.5 m/s and 3 mm thickness .

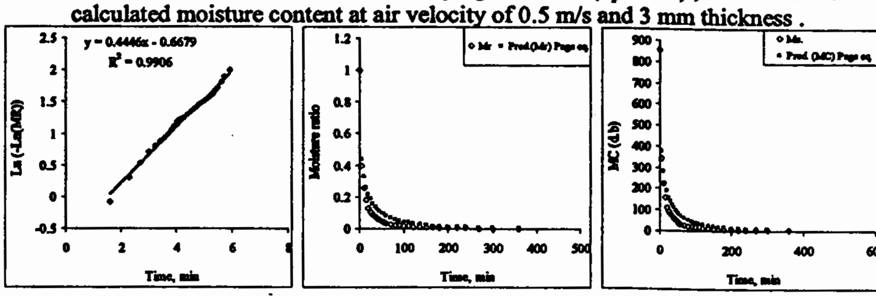


Figure (15): Determination method of drying constants (k_p and u) , measured and calculated moisture content at air velocity of 2 m/s and 3 mm thickness .

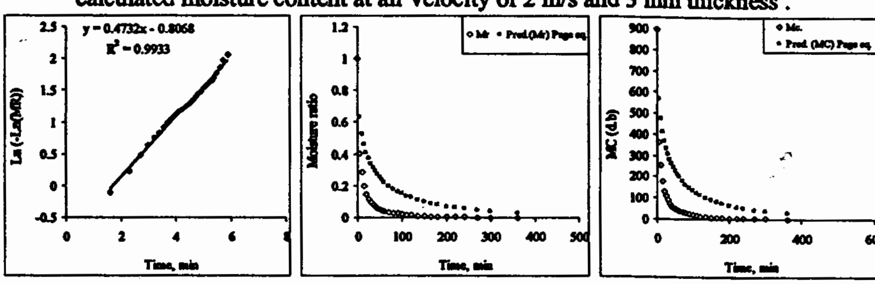


Figure (16): Determination method of drying constants (k_p and u) , measured and calculated moisture content at air velocity of 0.5 m/s and 5 mm thickness .

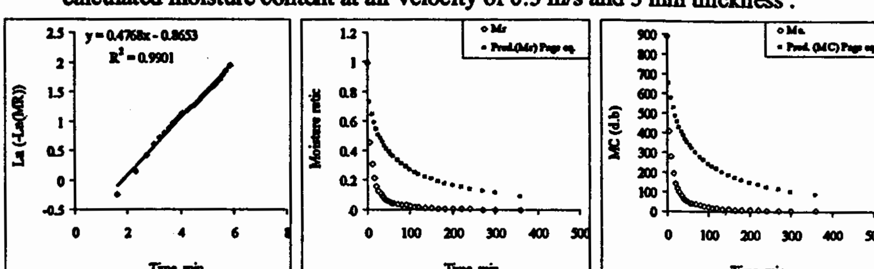


Figure (17): Determination method of drying constants (k_p and u) , measured and calculated moisture content at air velocity of 2 m/s and 5 mm thickness .

CONCLUSIONS:

1- The reduction in tomatoes moisture content was decreased with the increase of both slices thickness and drying air velocity.

2- Drying rate decreases continuously with diminishing moisture content and was much lower with 0.5 m/s air velocity and 3 mm slice thickness.

3- The maximum temperature recorded inside the dryer chamber was 56 °C when the corresponding ambient temperature and relative humidity of 34 °C and 30.8%, respectively with 3 mm thickness and 0.5 m/s air velocity.

4- The drying time was highly influenced by the weather parameters mainly temperature induced by solar insolation.

5 The drying rate constant 'k' value decreased with an increase in slice thickness and air velocity for both the simple exponential and Page drying models.

6- The drying rate constant 'u' value decreased with an increase in slice thickness and air velocity.

6- There is a good agreement between the experimental moisture ratios and the predicted values during tomato slices drying.

7- Both the simple exponential and Page drying models could satisfactory describe the drying behavior of tomato under the tested ranges of experimental treatments. While, the Page's model was found to be more appropriate for describing the drying behavior of tomato and calculating the change in tomato moisture content during the drying process.

8- Drying with solar energy was found to give a higher coefficient of determination.

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الملخص العربي

دراسات هندسية على تجفيف الطماطم

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تهدف الدراسة الي اختبار وتقييم نوع من المجففات الشمسية (يعمل بنظام الدفع الجبري للهواء) لتجفيف الطماطم وذلك تحت ظروف التشغيل المختلفة والتي تشمل سمك شريحة الطماطم (٣,٥مم)وسرعة الهواء(تحت الظروف المناخية المصرية و اختبار نموذجين للتجفيف (simple exponential and Page model's) لوصف سلوك عملية التجفيف والتنبؤ بالتغير في المحتوي الرطوبي للطماطم.

أهم النتائج :

١- وصلت أعلى درجة حرارة داخل غرفة التجفيف الى ٥٦ درجة مئوية فى حين كانت درجة الحرارة الخارجية ٣٤ درجة مئوية و الرطوبة النسبية حوالى ٣٠% و ذلك مع سمك ٣ مم و سرعة هواء ٠.٥ م/ث.

٢- نقص الرطوبة قل مع زيادة سمك الشريحة من ٣ الى ٥ مم و زاد مع زيادة سرعة الهواء من ٠.٥ إلى ٢ م/ث.

٣- انخفض معدل التجفيف مع سمك الشريحة من ٣ الى ٥ مم و سرعة الهواء من ٠.٥ م/ث.

٤- قل ثابت التجفيف (k_s) بزيادة سمك الشريحة وسرعة هواء التجفيف.

٥- قل ثابتا التجفيف (k_p) و (u) بزيادة سمك الشريحة وسرعة هواء التجفيف.

٦- وصفت كلا المعادلتين المختبرتين التغير في المحتوي الرطوبي لشرائح الطماطم أثناء عملية التجفيف بشكل مرضي. بينما تنبأت معادلة بيج بالتغير في المحتوي الرطوبي لشرائح الطماطم بشكل أكثر ملائمة بالمقارنه بالمعادلة البسيطة.

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