

DEHYDRATION OF ONION SLICES USING IR-REFRACTANCE WINDOW DRYING SYSTEM

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ABSTRACT

The aim of this research work was to study the drying behavior of onion slices using infrared radiation refractance window drying system, which the infrared radiation passed through plastic membrane surface, where the water in the moist product creates a window, that allows for the passage of infrared energy and heat behaves as it and directly transferred to water present in the product, the water in the product on the plastic membrane surface evaporates, and the window of infrared energy closes and refracts back into the heated source, no longer exposing the product to heat and good quality product.

The experiments of this work carried out at food engineering and packaging research dept., Food Techn. Res. Institute, Agric. Research center. The drying behavior of onion slices using suggested dryer was examined and simulated for three different thin layer drying models (Page, modified Page and Hendreson and Padis).

Four levels of radiation intensity (1100, 1750, 2400, 3050 W/m²) and for levels of drying air velocity (0.1, 0.5, 1 and 1.5 m/s) were studied at 45 °C temperature and 20 % relative humidity.

The results showed that :

The recorded drying time for drying whole onion slices from an initial moisture content of about 612 - 614.28 % d.b. to a final moisture content of about 13.75 - 15 % d.b. were 50 - 140 minutes under different drying parameters.

- The following equation can describe the relation ship between drying time (T), radiation intensity (I) and air velocity (V) with the best fit :

$$T = 80 + 100V - 1600 I, \quad (R^2 = 0.9911)$$

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- The thermal efficiency of the IR-refractance window drying system was varied between 54.47% to 46.43% , specific energy consumption varied between 4.39 KJkg^{-1} to 5.15 KJkg^{-1} under different drying parameters.
- The total capacity of the dryer is a bout 0.326 Kg/h the calculated operation cost of the dryer approaches about 8.89 LE/kg of dried whole onion slices .

INTRODUCTION

Brenden er al. (1999). Compared the following pilot plant dryers namly : Refractance window, drum, spray and freeze dryers , using energy efficiency, Beta carotene, total carotene, ascorbic acid (vitamins) and color retention of strawberries and carrots. They reported that the choice of strawberries and carrots was due to their importance as a source of vitamin and pro – vitamin A (B – carotene) respectively .

They summarized their results as follows . Energy efficiencies 27.9 – 47.6 % obtained for different drying conditions for the refractance window system were comparable to or slightly higher than the hot air methods (30 – 40) % reported in the reported in the literature.

Vitamin C retention in refractance window dried strawberries were comparable to or higher than freeze – dried to a similar moisture content.

- Beta, Alpha and total carotene retention of refractance window dried carrots were comparable to freeze dried product and better than drum dried product.
- Color degradation in refractance window dried products was comparable to or slightly less than that of freeze dried products .

Feng et al.(1999). Reported that drying kinetics in refractance window system for tested liquid foods generally followed the trend obtained for similar products using other drying methods, with no apparent constant rate period.

- **Boudhrioua et al. (2003)**. Found that major disadvantages of hot air drying of foods are low energy efficiency, quality loss and lengthy drying time during the falling rate period. Because of the low thermal conductivity of food materials, heat transfer to the inner sections of food during conventional heating is limited. The desire to eliminate this

problem, prevent significant quality loss, and achieve fast and effective thermal processing has resulted in the increasing use of infrared and microwaves for food drying. **Dilip and Pankaj (2004)**. Showed that infrared drying technology is based on a property of water to absorb infrared (IR) radiation. Infrared radiation has a wavelength range from 0.75 to 100 μm subdivided into short-wave IR (0.75-2 μm), medium wave IR (2-4 μm), and long-wave IR (4-100 μm). The mechanism of bio-product drying is mass diffusion of water out of the bio-product and into the surrounding air. The infrared red rays penetrate to certain depth into the bio-products and increase its temperature. As a result of this temperature increase, the diffusion rate of water through the bio-product is increased and the water is vaporized at the surface of the material. The moisture is taken up by the drying air and provides in a fast rate of drying. **Hebbar et al. (2004)**. Developed a combined infrared and hot air heating system for drying of vegetables. A conveyor based drying system having three chambers was fitted with mid-infrared (MIR) heaters for irradiative heating. Through-flow hot air circulation was also provided for convective mode heating. The system was designed to operate under infrared, hot air and combination mode independently. The performance evaluation studies indicated that combination drying of carrot and potato at 80 °C with air at a velocity of 1 m/s and temperature of 40 °C reduced the drying time by 48%, besides consuming less energy (63%) compared to hot air heating. Combination drying also gave better results over infrared heating alone. The energy utilization efficiency of the dryer was estimated to be 38% for both carrot and potato drying.

Sharma et al. (2005). Reported that the drying time reduced dramatically with increase in infrared power. They also, observed increased drying rates of food products with increasing power supply to infrared heater. The required drying time to reduce the moisture content of onion slice to about 0.06 g water / g dry matter at infrared power of 300, 400 and 500 W was about 9, 7 and 4 hours, respectively. The vapor pressure is considered to be a function of both temperature and moisture content. The increase in infrared power might have caused a rapid increase in the temperature at the product surface, resulting into an increase in the water vapor pressure inside the product and thus in higher

drying rates. **Kathira van Krishnamurthy, et. al (2008)**. Infrared(IR) heating provides significant advantages over conventional heating, including reduced heating time, uniform heating, reduced quality losses, absence of solute migration in food material, versatile, simple, and compact equipment, and significant energy saving. Infrared heating can be applied to various food-processing operations, namely, drying, baking, roasting, blanching, pasteurization, and sterilization..

MATERIALS AND METHODS.

Material:

- The experimental dryer:

Figures (1) illustrates the elevation and sid view of the design dryer used for experimental work.

The dryer consists of the following three main parts:

- The Lower Cabinet:

Is made of a double wall galvanized steel sheet with a thickness of 1.5 mm, the space between both of the two walls is filled with glass wool insulator has a density of 16 kg/m^3 . The cabinet has dimensions of 2.7 m length \times 0.44 m width \times 0.5 m height The lower cabinet contains the following parts:

- A conveyor belt made of transparent polyester with a thickness of 10 micron. This type of material allows highly IR ray penetration and can bear intensity of 4500 W/m^2 and tensile strength of 70 N. The belt gets its motion manually
- A group of nine 250 W IR heating units (elements) are assembled under the conveyor belt using (L) shape 1.5 mm thickness galvanized steel holders in a way allows them sliding toward or outward the belt direction.
- the IR ray intensity was controlled by a dimmer.
- A stainless steel sliding sheet with a thickness of 1 mm assembled to the end of the cabinet for receiving and directing the outlet dried material.

A brush is assembled below the plastic membrane surface for cleaning it of residues. - Has been allocated a small room in the cabin the bottom

contains on A single air heating element 2000 Watt power are often used to heat the air inside to 45 °C.

- The upper Cabinet:

Has a conical shape with dimensions of $1.7 \times 0.44 \times 0.85$ m is made of a double wall galvanized steel sheet with a thickness of 1.5 mm, the space between both of the two walls is filled with glass wool insulator has a density of 16 kg/m^3 .

The upper cabinet contains the following parts:

- A group of eight 250 W IR heating units (elements) are assembled above the conveyor belt (in the lower cabinet) using (L) shape 1.5 mm thickness galvanized steel holders in a way allows them sliding toward or outward the belt direction.

Both groups of IR units above and under the plastic membrane surface are placed in a reciprocal order that allows the similarity of distributing the ray intensity on the transparent belt total area that is controlled by a Dimmer.

- A lateral box contains control units for controlling the plastic membrane surface linear speed, ray intensity and air velocity .

- Air Blower:

- An air blower and a PVC flexible tube was used to exhaust the moist air that is controlled using a disc shape damper assembled on the shaft of a stepper motor. The damper gets its motion from a stepper motor

- Control System:

Control system was used to control the different functions of the dryer and is connected to a desk PC with a special designed software. The control system consists of the following devices:

- power Suply:

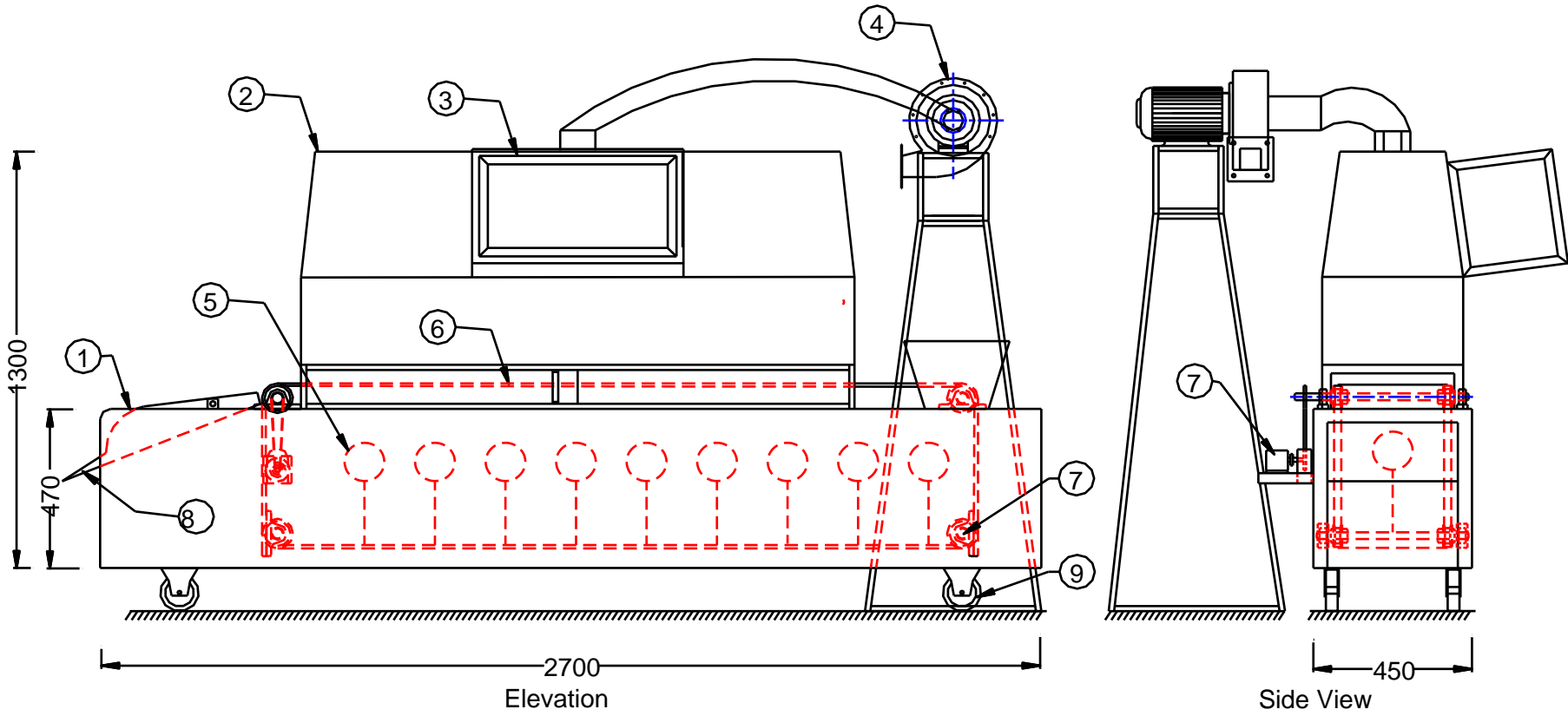
A control device was used to control the direction and the angle of the stepper motor disc (damper) in order to control in velocity of moist air .

- Dimmer for Controlling the IR Ray Intensity:

A dimmer was used to control the ray intensity of the IR heating elements

2- Tested Crop:

The white onion the initial moisture content of the freshly harvested ranged from 612 % to 614 % (dry basis) and the drying runs were stopped when the final moisture content reached about 8 % (w.b).



Figures (1) Experimental IR-Refractance window .

3-Measuring equipment :

- Ray Intensity:

Ray intensity was measured by using Campbell Stokes Sunshine Recorder .The specifications of the instrument are listed in Table (1).
Technical Details Adjustment for latitude :Table (1).

Tropical – 45 to 65 N or S
Sphere: 102mm + / - 1.3mm diameter.
Focal length for sodium D light, 74.9mm +/-0.25mm
Dimensions : 240 x 187 x 165mm
Weight: 4.3Kg

- Digital velocity stick :

It was used to measured air velocity . It has the following specifications are. Technical data:

Model : It is model (testo 405-V I)

Measurement range (0 to 400 m / min)

Accuracy : (± 0.10 m / min) .

3.1.6.3 Digital temperature stick :

It was used to measure air temperature. Its specifications are .Technical data: Model : It is model (testo 905-T I)

Sensor thermocouple ; type k
Measurement range : -50 to + 350 °C:
short – term to + 500 °C
Accuracy:(referred to calibration temperature of $\pm 1^\circ\text{C}$.

- Digital humidity stick:

It was used to measure air humidity . It has the following specifications are. Technical data :

Model : It is model (testo 605-H I)

Sensor thermocouple ; type k

Measurement range : 5 to 95 % RH / -20 to +70 °C

Accuracy : (System accuracy at ± 3 % RH) .

- Dried Material Colour :

Dried material Colour was measured by using Hunter Color-meter .

- Cutting Machine :

Slices of onion slices were prospered using a cutting machine The machine consists mainly of two parts : a movable part and a fixed part . The movable part had a circle slicing knife make the needed shape and dimension of slices.

- A static balance :-

It was used to weight Initial and final weights of each sample with an accurate to(0.01 gm).

- Material thickness measurement :(vocalic) :-

It was used to measure the thickness of the dried material , It is an important parameter for the drying experiments .

- Stop watch :-

A Stop watch was used to measure the drying time by minutes .

- Electric Current Ampere and Volt:

The electric current ampere and volt for the IR heating elements, air heating element, air blower motor and damper stepper motor was measured by using an electronic Avometer .

4- Methods:**b) Preparation of the onion (Type : White) .**

1) Peeling the onion by using special machine .2) Washing. 3) Weight the peeling onion by digital balance. 4) Chopping the weight onion to 1 mm slices by thickness chopping machine. 5) Saturated the onion slices in mita sodium sulfite ($\text{Na}_2 \text{S}_2 \text{O}_5$) by concentration of 0.3 % duration 5 minutes .6) Washing the onion slices under way water to takeout the saturate water. 7) Put the slices in the dryer (100 gm).

5- Experimental proceeding :

Multie experiments were conducted to study the drying of onion slices using IR-refractance window,

The samples of products prepared as follows.

All the experiments were conducted at inlet air of 45C° and at relative humidity 20 %. Four levels of radiation 1100 – 1750 – 2400 and 3050 W/m^2 and four levels of air velocity of 0.1 – 0.5 – 1 and 1 M / s were

examined .The thicknesses of products were 6 mm. Drying behavior, specific energy, thermal efficiency, quality of final product and cost analysis were studied for products using window drying method.

6- Measurements and Calculations:

3.2.2.1 Moisture content of products :

by vacuum oven at 343 k° until (A. O.A.C, 1985)

- Specific energy consumption :-

The specific energy requirement for moisture removal was calculated according the following equation :

$$\text{Sp.Energy} = \frac{\text{Total energy consumption (Kj)}}{\text{Quantity of lost water (Kg)}} \dots\dots\dots 3 - 1$$

The energy consumption during the drying process is the sum of energy required for heating the ambient air and the supplied net infrared energy. For each experimental run, the energy consumption was calculated using the following relationship (Afzal et al. (1999)

Energy consumption = 3.6 P D = 3.6 I V D (Kj)..... 3 - 2

Where:-

- P = power consumption W
- I = amperage A
- V = voltage V
- D = drying time h

- Thermal efficiency of the dryer :-

In order to evaluate the overall performance of the dryer. Thermal efficiency was determined from actual drying tests. The thermal efficiency (η) was calculated using the following relationship according to Jindal and Reyes (1987) .

- quality measurements:

- Rehydration ratio: The rehydration capacity was evaluated according to Sacilik and Unal, (2005).

- Colour of the dried onion slice:

The appearance of both fresh and dehydrated slices was assessed by a colour-difference meter. using a Hunter Lab Colorimeter. According to (Sharma and Prasad, 2006).

- Cost analysis.

The operation cost of the best designed dryer was calculated according to a modified form of the equation of Awady, (1993). This equation is:

$$C = (P/H) (1/Y + I/2 + T + M) + e + (s/144) \dots\dots\dots 3 - 3$$

Where: **C** (total hourly cost), **P** (initial price or capital of dryer .

H (estimated yearly-operating hours. **Y** (estimated life-expectancy of dryer in years . **I** (investment or overhand rates, **T** (taxes and overhead rates, **M** (maintenance and repairs ratio to capital head. **E** (electric-energy cost .

$$\text{Actual machine production productivity (Kg / h)} = \frac{\text{Mass onion slices (Kg)}}{\text{Time of drying time (h)}} \dots\dots\dots 3 - 4$$

$$\text{Operation cost (LE / Kg)} = \frac{\text{Machine cost (LE. / h)}}{\text{Actual machine production productivity (Kg / h)}} \dots\dots 3 - 5$$

Table (2): Values of drying time , operation cost , capacity of dryer (Kg/h) and drying cost per kg of product when using radiation intensity 2400 W/m² and air velocity 0.1 m/s.

Type of product dried	Drying time (h)	Operating cost of dryer (LE/h)	Capacity of dryer (Kg/h)	Drying cost per kg of drying product (LE/Kg)
Onion slices	1.08	1.79	0.592	3

4- RESULTS AND DISCUSSION

4.2. IR- Refractance Window Method for Drying Onion Slice:

4.2.1. Behavior of Refractance Window Drying System of Onion Slice .

The different air velocity and different infrared radiation on moisture content , drying rate and moisture ratio of onion slice at thin layer (thickness 4 mm) of refractance window drying system all the experiments were conducted at inlet air temperature of 45 °C

at relative humidity 20 %, with four levels of radiation intensity (1100 - 1750 -2400 and 3050 W/m²) and four levels of air velocity of (0.1–0.5 –1 and 1.5 M/s) were also examined. The thicknesses of onion slice were 4 mm.

4.2.1.1. Influence of radiation intensity and air velocity on drying curves :-

The change in moisture of onion slice as relate time for different air velocity and different radiation intensity in IR-refractance window drying system are illustrated in figures (4-1). As shown in figure that the moisture content of onion slice decreased continuously with time at increasing radiation intensity and decreased air velocity .

Figures (2) and (3) show the variation of drying rate with change in onion slice moisture content or drying time. The figures show that , the drying rate of onion slice was decreased with the decrease of moisture content or in other words with the increase of drying time due to the reduction in onion slice moisture content.

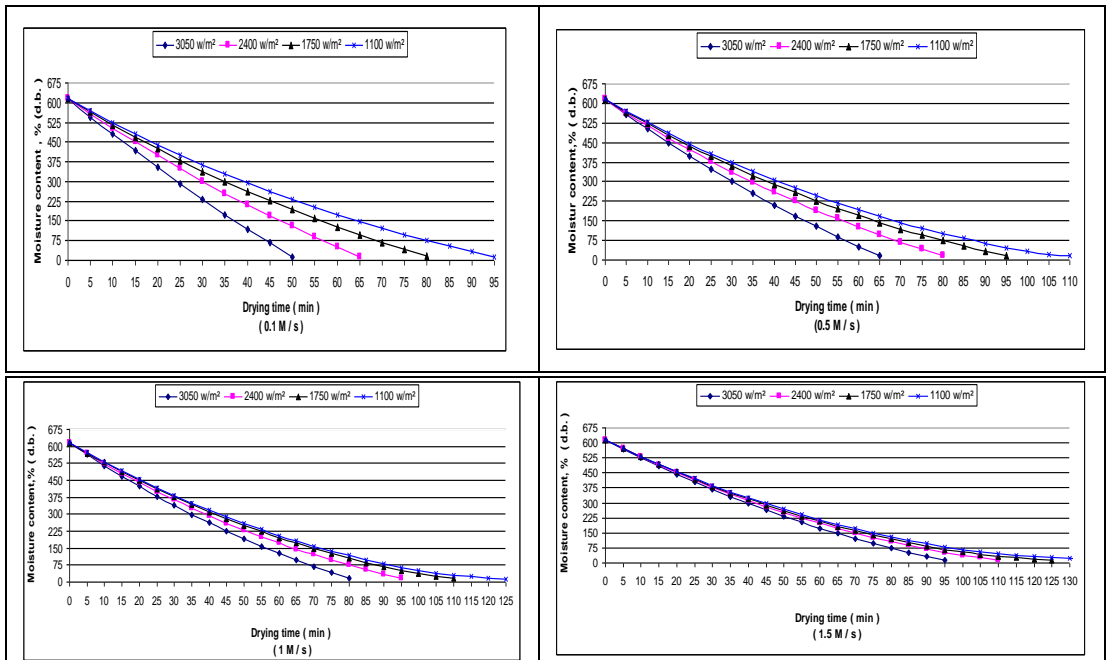


Figure (2): Variation of moisture content of onion slice as related to drying time at different air velocity and at different intensity in IR-refractance window drying system.

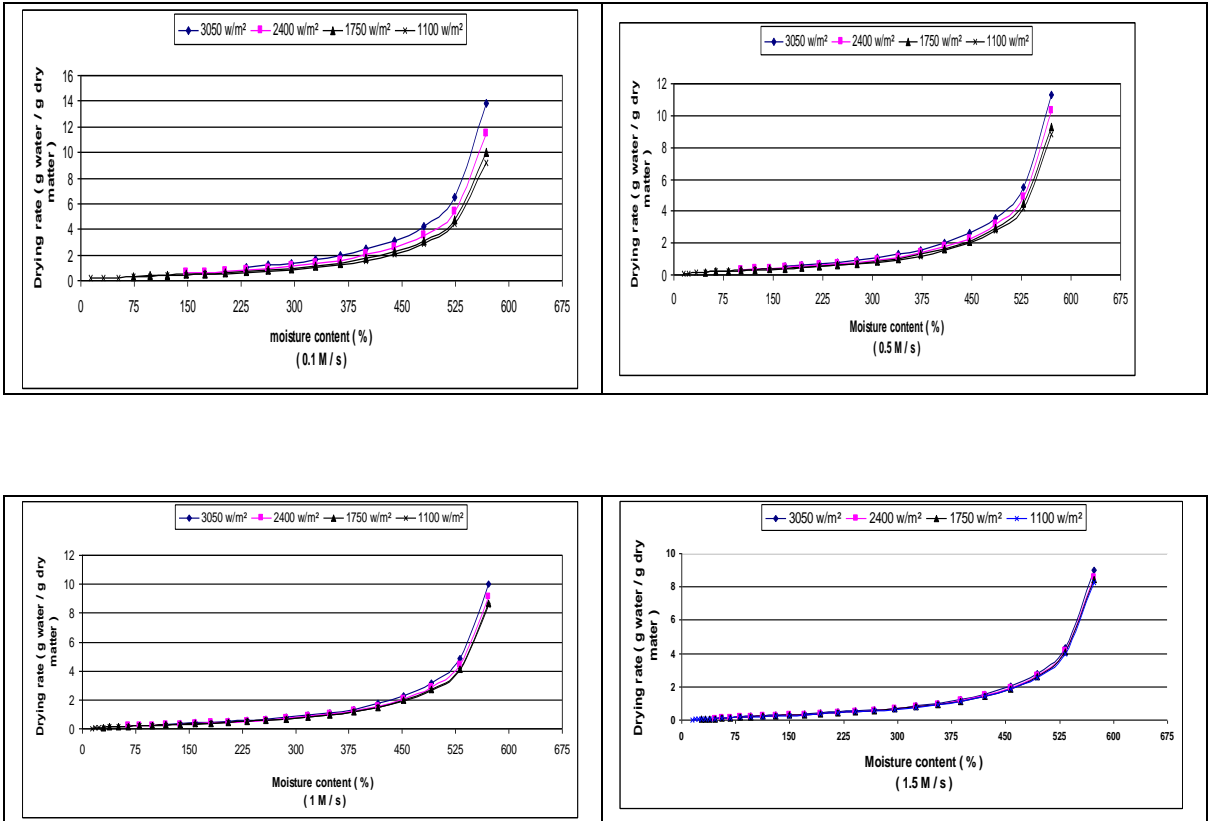


Figure (3): Variation of drying rate of onion slice as related to moisture content at different air velocity and at different intensity in refractance window drying system

In these figures the constant rate drying period is absent; the drying process took place in the falling rate period. In general the drying rate of onion slice increased with the increase of radiation intensity and decrease of air velocity. At the minimum air velocity of 0.1 m /s and radiation intensity of 1100 , 1750 , 2400, and 3050 W / m ² the overall average drying rate during the drying process were 1.450 , 1.844 , 2.502 and 3.741 g water / g dry matter respectively, while, at the maximum air velocity of 1.5 m/s and radiation intensity of 1100 , 1750, 2400, and 3050 W / m ² the corresponding drying rate were 0.906 ,1.032 , 1.191 and 1.438 g water/g dry matter respectively.

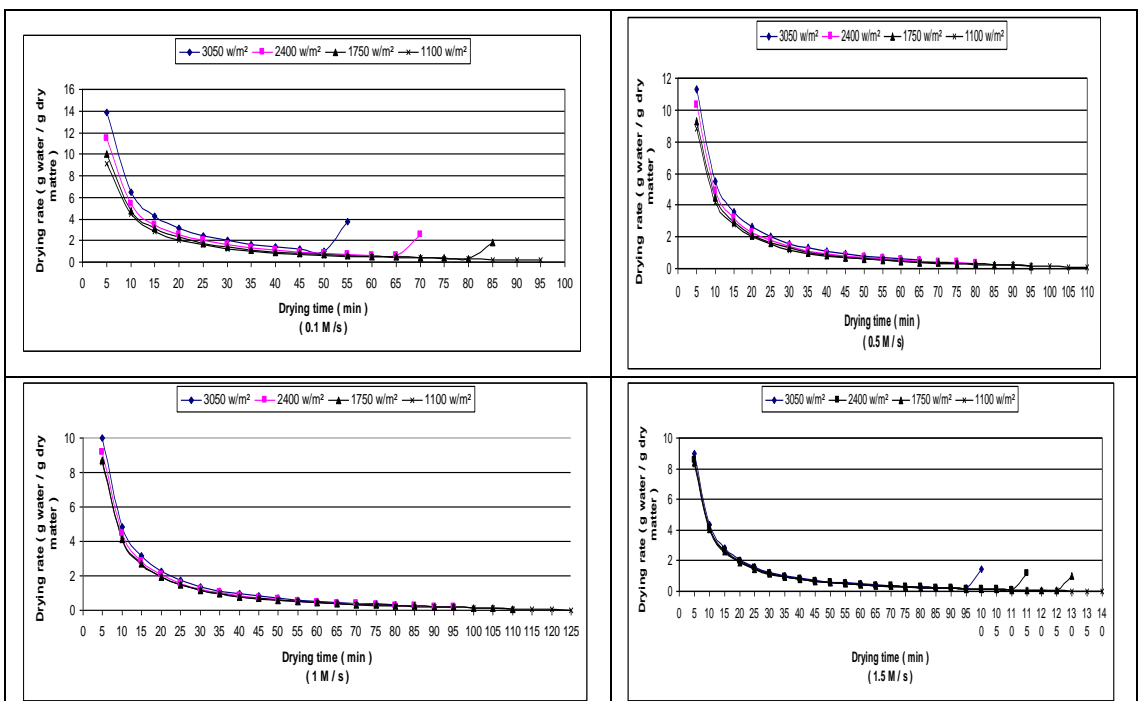


Figure (4): Variation of drying rate of onion slice as related to drying time at different air velocity and at different intensity in refractance window drying system.

The moisture ratio against time for thin layer drying of onion slice at different radiation intensity and different air velocity for IR-refractance window drying system are shown in figure (4). The effect of increasing the radiation intensity on drying rate, when air velocity was constant is evident. The figure (5) show that, the moisture ratio decreased with the increased of drying time. The reduction rate of moisture ratio increased with the increasing of radiation intensity while it was decreased with the increase of air velocity.

2. Influence of radiation intensity and air velocity on drying time(T).

Figure (6) illustrate the relation between drying time and both intensity and air velocity for IR-refractance window drying system. Generally it can be observed that, the drying time decreased with the increasing of radiation intensity and decreasing of air velocity. This condition may be due to the radiation intensity increased; high heat flux provided by the infrared heating causing rapid rise of onion slice temperature toward the end of the drying process, with corresponding increase of the drying rate and hence decreases of drying time. The increase in drying time by increasing air velocity may be due to lowering of onion slice temperature and hence the drying rate as previously mentioned the observed onion

slice temperature decreased with the increase in air velocity at all levels of radiation intensity.

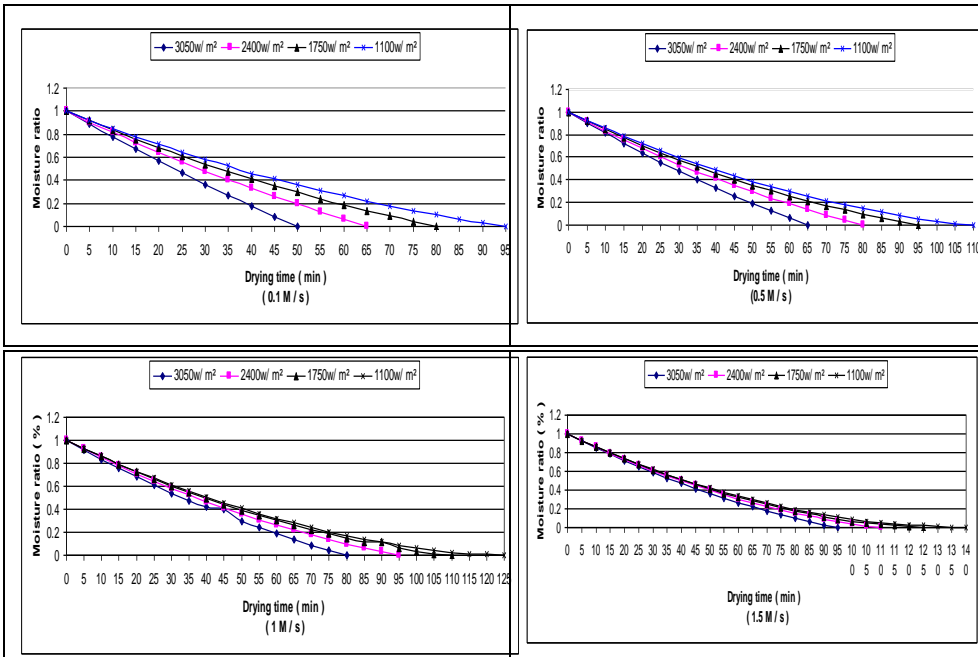


Figure (5): Variation of moisture ratio of onion slice as related to drying time at different air velocity and at different intensity in refractance window drying system.

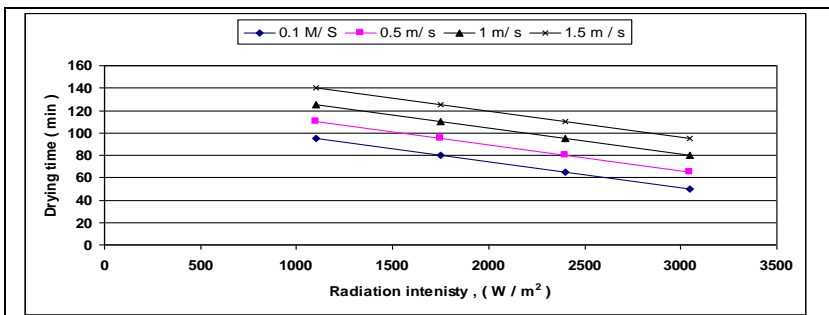


Figure (6): - The Effect of different radiation intensity and different air velocity on drying time of onion slice in IR-refractance window drying system.

Changing the radiation intensity from 1100 to 3050 W / m² at the minimum air velocity of 0.1 m/s decreased the drying time form 95 to 50

min. while at the maximum air velocity of 1.5 M / s the drying time decreased from 140 to 95 min. A multiple regression analysis was proceeded to describe the relationship between the drying time (T), radiation intensity (I) and air velocity (V) for refractance window, the regression equations for the best fit was as the following :

$$T = 80 + .01V - 2195 I, \quad (R^2 = 0.9911) \dots\dots\dots 4 - 1$$

3. Specific energy consumption , thermal efficiency and quality of refractance window drying system of Onion Slice.

Specific Energy Consumption :

Figure (7): illustrated the effect of infrared radiation intensity and air velocity on the specific energy consumption of IR-(R.W.) drying system. The specific energy consumption increased with the increasing radiation intensity. Changing the radiation intensity from 1100 to 3050W/m².

At the minimum air velocity of 0.1 m/s increased the specific energy consumption 4.39 to 5.15 KJkg⁻¹ of water while at the maximum air velocity of 1.5 m/s the specific energy consumption increased from 6.48 to 9.82 KJkg⁻¹ of water of water of IR- (R.W.) drying system.

In general, the specific energy consumption increased by increasing air velocity , as a result of lowering the onion slice temperature and hence decreasing the drying rate.

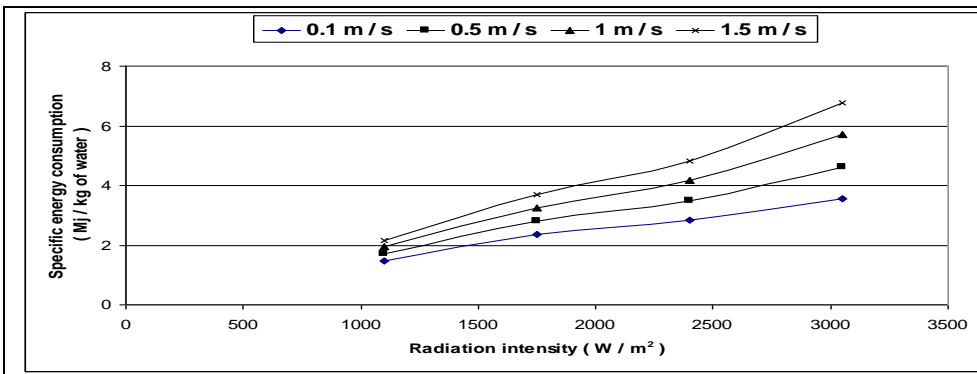
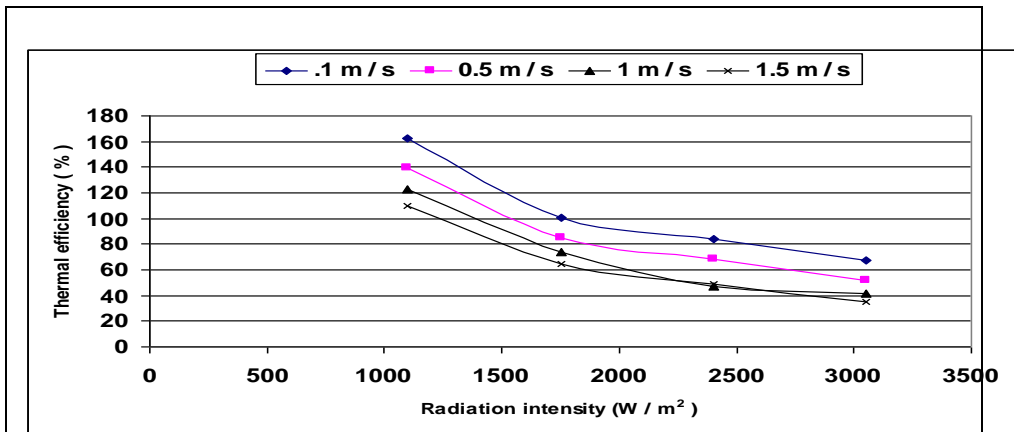


Figure (7): Specific energy consumption as related to different radiation intensity and different air velocity in refractance IR-window drying system of onion slice.

4-Thermal Efficiency :-

Figure (8): show the effect of radiation intensity and air velocity on thermal efficiency of IR- (R.W.) drying system. The thermal efficiency increased by the decreasing radiation intensity and decreasing air velocity.

Increasing the radiation intensity from 1100 - 3050 W/ m² at the minimum air velocity of 0.1 m/s decreased the thermal efficiency from 54.47 to 46.43 % respectively on the other hand , at the maximum air velocity of 1.5 m/s the thermal efficiency decreased from 36.85 to 24.39 % of IR-(R.W.) drying system. The decreased of thermal efficiency with increase of radiation intensity may be due to the increase of total specific energy consumption with increasing radiation intensity. Mean while, increasing of total specific energy consumption with the increase of air velocity decreased the onion slice temperature and hence, decreasing the drying rate and increasing the drying time and total specific energy consumption which finally the thermal efficiency decreased.



Figure(8): Thermal efficiency as related to different radiation intensity and different air velocity in refractance window drying system of onion slice.

Onion Slice Quality :

a. The Rehdration Ratio of Onion Slice :

Figure (9) present the effect of infrared radiation intensity and air velocity on the rehydration ratio of onion slice of IR- (R.W.) drying system. The rehydration ratio increased with the increasing of infrared

radiation intensity. This is due to the increased rate of moisture removal with the increase of radiation intensity which causes less shrinkage of the dried onion slice thus facilitating the rehydration process.

Changing the radiation intensity from 1100 to 3050 W / m² at the minimum air velocity of 0.1 m/s increased the rehydration ratio from 95.1 % to 95.6 % respectively while, it was increased from 91.4 % to 94.4 % at the maximum air velocity of 1.5 m/s . The decrease of rehydration ratio by the increase of air velocity may be due to the lower rate of moisture removal from onion slice as a result of onion slice temperature reduction which cause a high shrinkage of the dried onion slice .

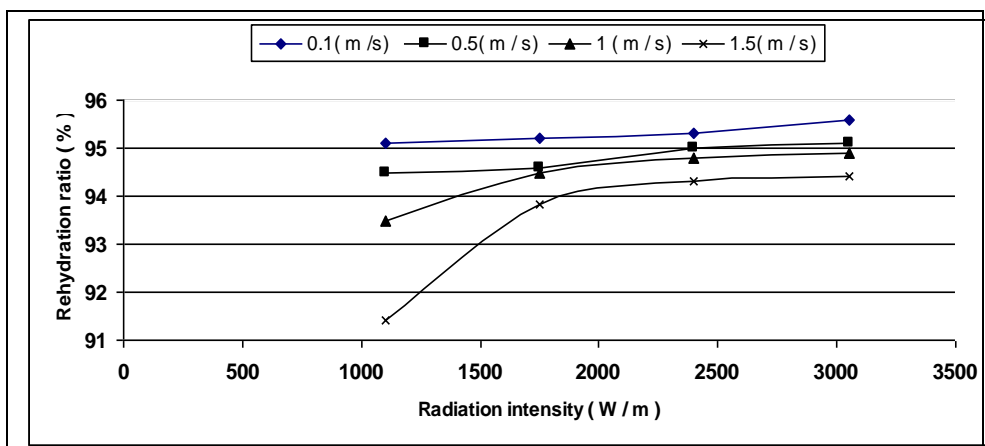


Figure (9):-The effect of different radiation intensity on the rehydration ratio (%) of onion slice at different air velocity (0.1 - 0.5 - 1 - 1.5 m / s) in refractance window drying system.

b. Colour change of Onion Slice:

Figure (10) show the effect of infrared radiation intensity and air velocity on the colour difference of onion slice of refractance window drying system. The colour difference increase of infrared radiation intensity. Changing the radiation intensity from 1100 to 3050 W / m² at the minimum air velocity of 0.1 m / s increased the colour difference from from 21.5 to 28 . While at the maximum air velocity of 1.5 m / s the colour difference increased from 12 to 20. Also the colour difference increased by the increase of air velocity. This is because the decrease of onion slice temperature by the increase of air velocity.

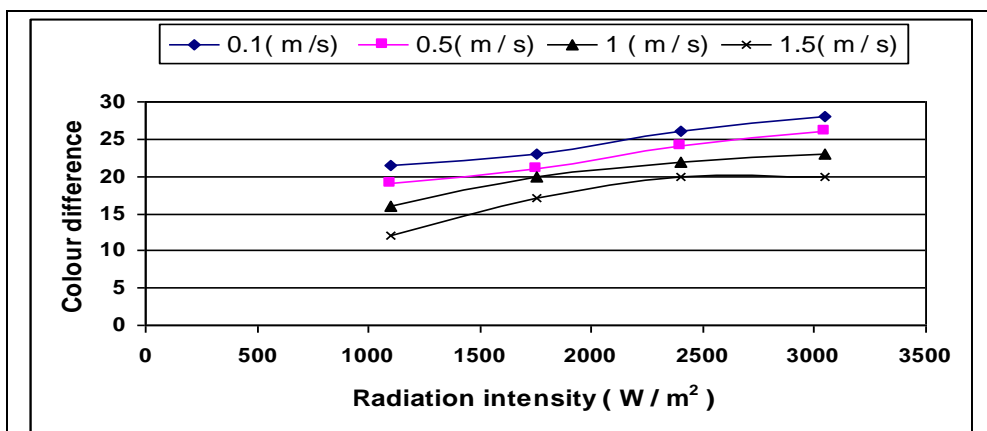


Figure (10):-The effect of different radiation intensity on the Colour difference (ΔE) of onion slice at different air velocity (0.1- 0.5 -1- 1.5 m/s) in refractance window drying system.

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الملخص العربي

تجفيف شرائح البصل باستخدام نظام التجفيف الانعكاسي للأشعة تحت الحمراء

سمير أحمد طایل^١ حسنى سلطان القطرى^١ خالد سيد ناجى^٢ عمر شحات يونس^٣

أجريت هذه الدراسة بغرض تصنيع مجفف يعمل بنظام التجفيف الانعكاسي للأشعة تحت الحمراء وذلك لتجفيف شرائح البصل ويعتمد التجفيف الانعكاسي للأشعة تحت الحمراء على نفاذ الأشعة من خلال سطح غشائي بلاستيكي من البولى إستر للعمل على تجفيف المنتج الرطب الموجود فوق السطح. وعندما يتم جفاف المنتج يعمل سطح البولى إستر بالأشعة مع المنتج الجاف على عكس الأشعة وعدم نفاذها إلى المنتج مما يحافظ على جودته.

إجريت هذه الدراسة بقسم بحوث هندسة تصنيع وتعبئة وتغليف الأغذية - معهد بحوث تكنولوجيا الأغذية - مركز البحوث الزراعية.

تمت دراسة سلوك تجفيف شرائح البصل فى طبقة رقيقة باستخدام المجفف المقترح لأربعة

- مستويات للطاقة (١١٠٠، ٢٤٠٠، ١٧٥٠، ٣٠٥٠ وات / م^٢)، وأربع مستويات لسرعة الهواء (١، ٥، ١٠، ٢٠ م/ث، ١، ٥، ١٠ م/ث) مع ثبات درجة حرارة الهواء عند ٤٥ درجة مئوية.

أظهرت النتائج المتحصل عليها أن :

- زمن تجفيف شرائح البصل من محتوى رطوبى ٦١٢ - ٦١٤ % على أساس جاف إلى محتوى رطوبى نهائى ١٣ - ١٥ % على أساس جاف هو ٥٠ - ١٤٠ دقيقة تحت العوامل الدراسية المختلفة.
- تم أستنباط معادلة رياضية للعلاقة بين زمن التجفيف (T) وكلا من شدة الأشعاع I (وات / م^٢) وسرعة الهواء V (م / ث) كالتالى:

$$T = 80 + 100V - 1600 I \quad (R^2 = 0.9911)$$

- أعطت معادلة التجفيف هندرسون وبادس أعلى درجة دقة فى التنبؤ بالمحتوى الرطوبى اثناء تجفيف شرائح البصل باستخدام المجفف
- تراوحت الكفاءة الحرارية بين ٥٤,٤٧ % ، ٤٦,٤٣ % كما تراوحت الطاقة الحرارية بين ٤,٣٩ كيلو جول / كجم ، ٥,١٥ كيلو جول / كجم تحت العوامل الدراسية المختلفة للتجربة.
- شدة الأشعة ٢٤٠٠ وات / م^٢ وسرعة هواء ١ م / ث أعطت أعلى خصائص جودة لشرائح البصل المنتج وذلك من حيث اللون ونسبة التثريب.
- تكاليف تشغيل المجفف لشرائح البصل الذى سعته الإنتاجية فى الظروف المثلى ٥٩٢ كجم / ساعة تعادل ٣ جنية / كجم من شرائح البصل.

(١) أستاذ متفرغ بقسم الهندسة الزراعية - كلية الزراعة جامعة الأزهر .
(٢) باحث أول ورئيس قسم بحوث هندسة تصنيع وتعبئة وتغليف الأغذية - معهد بحوث تكنولوجيا الأغذية - مركز البحوث الزراعية.
(٣) باحث مساعد بقسم بحوث هندسة تصنيع وتعبئة وتغليف الأغذية - معهد بحوث تكنولوجيا الأغذية - مركز البحوث الزراعية.