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DRYING ONION USING A SOLAR DRYER WITH AN AUXILLARY HEATING SYSTEM

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ABSTRACT

In the present study two different drying systems for drying onion slices (4 mm thick) were tested , namely: forced convection solar dryer (traditional dryer) and forced convection solar dryer with an auxiliary heating system in which drying air temperature (60 ± 1°C) can be controlled. The two dryers were designed, constructed and evaluated based on average drying performance, which can be defined as the useful energy used for evaporating water from the onion slices to the integrated solar energy incident on the dryer's collector surface area , drying coefficient , drying costs and the pay-back period . The average drying performance , drying coefficient and costs for the dryer with auxiliary heating system were 1.37 , 0.16 and 361.16 LE/ton compared to 0.96 , 0.055 and 1185.7 LE/ton for the conventional one . The cost-benefit analysis shows that the pay-back period for the auxiliary type dryer was 144 operating hour compared to 452.24 operating hour for the traditional type dryer.

INTRODUCTION

Onion drying

Al-Katary (2000), studied air-properties of a thin layer drying system for onion slices 0.5 mm thick using drying air temperature of 60 °C and 10.5 % relative humidity with flow rate of 2.4 m^3/h . He concluded that after two hours from beginning of drying process (0.286 of total onion drying time) , properties of the drying air are suitable for reuse in the drying process . Thus after two hours air may pass through either the same onion sample or a subsequent one conserving about 80.45 MJ/kg of exhaust energy lost in the ambient air , increasing drying efficiency about 67.62 % (from 18.38 to 86 %) .

Robertson (1978), and Hall (1980), reported that a drying period is required when onion are removed from the field with excess surface moisture . They also stated that onions have surface moisture when placed in storage case the relative humidity in the pile reached 100 % , thereby, encouraging the growth of rot-causing organisms .

Sharma and Nath (1991) , studied the sorption isotherms for predicting storage behavior of ten varieties of dried onion rings. They suggested that optimal storage conditions for dehydrated onion rings to about 1 % moisture content and at 43.9 % relative humidity .

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Sharma and Nath (1991), reported that demands for fresh and dehydrated onions have considerably increased over the last two decades. Ten onion varieties were dehydrated as 5 mm thick rings in an air cabinet dryer (65 ± 2 °C for seven hours). They stated that dehydration reduced pugency (as pyruvic acid) and ascorbic acid levels , and induced browning ; the extent of these changes depend upon variety .

Lewicki et al (1998), dried two different onion varieties (Oporto and Blonska) by a forced convection dryer at 60 °C and 2 m/s air velocity . Prior to drying , sliced onion were subjected to the following treatments : soaking in water ,dipping in starch solution supplemented either with ascorbic acid or Ca Cl_2 ; and dewatering by osmosis in sucrose solution . Drying of raw onion was used as control treatment. They found that both variety and pretreatment affected the course and rate of drying . They also mentioned that soaking in water and in starch solution either increase the rate of drying or have no effect on the kinetics of the process . They concluded that supplementing the starch with ascorbic acid or $CaCl_2$ adversely affected the rate of drying . Lewicki et al. (1998), dried onion slices 3 mm thick at 60 °C by convection and it was taken as a reference process . They found that increasing the air temperature increases the drying rate. They mentioned that effective diffusivity increases with increasing temperature but it is a strongly dependent on water content .

Drying efficiency of the solar dryers

Awady et al. (1993) defined the the useful heat of the solar drying system Q_u as :

$$Q_u = (Ww^* L) + (m_p Cp \Delta t) \quad \text{.......} (1)$$

Thanavi and Pandae (1987) , used the following expression for calculating the drying efficiency of a solar dryer at any time period ϕ to $\phi+\Delta\phi$:

$$\eta_d = (Q_u / A \int_{\phi}^{\phi+\Delta\phi} I_n \, d\phi) \quad \text{.......} (2)$$

where:

Ww : The mass of moisture removed , kg ;
L : The latent heat of water , kJ/ kg ;
m_p :The mass of product , kg ;
Δt :The temperature rise of product , °C ;
A :The surface area of drying bin , m^2 ;
I_n : The solar intensity of radiation $kW.m^{-2}$;
Cp : The specific heat of the product , kJ/kg °C .

Cost analysis

Imre (1986) reported that in solar drying systems saving obtained by avoiding environmental pollution , by quality improvement and increasing the energy effectiveness should be taken into account in economy evaluation. Awady et al. (1988) reported that the total cost per unit product is broken down into :

1) Fixed costs :

a) $$\text{Depreciation} = \frac{\text{Cost new} - \text{salvage value}}{\text{Total expected life in years}} \qquad (3)$$

(Salvage = 10 % of cost new)

b) Interest on investment =[0.5(Depreciable cost) + estimated salvage] x interest rate. ——— (4)

(Interest rate is assumed 0.08)

c) Taxes and insurance = [0.5 (Depreciable cost) + estimated salvage] x combined rate ——(5)

(combined rate = 1.5 %)

2) operating costs :

Operating costs are those that are directly related to use; they include :

a) Fuel ,power and utilization

b) maintenance and labor (maintenance = 3% cost new).

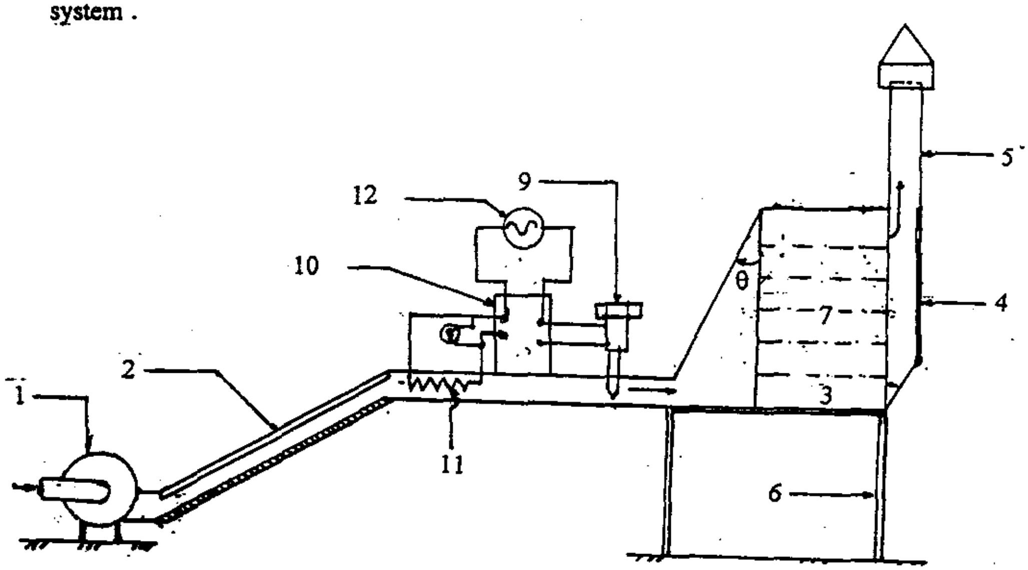
This research was carried out to study the possibility of using solar drying system (thin-layer drying) supplemented by auxiliary heating system for drying onion and compared it by a similar solar dryer designed without auxiliary heating system (traditional solar dryer). Specific objectives include :

1. Designing a low- cost solar drying system with a capacity of 15 kg onion slices which can be fabricated by farmers or craftsmen using simple tools and relatively cheap and avialable materials.
2. Evaluating the drying performance of the two drying systems tested.
3. Determination of the drying coefficient.
4. Evaluation of the drying costs required for one ton of dried onion and the pay-back period.

MATERIALS AND METHODS

1. Solar dryer construction

The dryer was constructed on the roof of the Ag. Eng. Dept., Al-Azhar Univ. It was 0.2 m^3 (0.5 m x 0.5 m x 0.8 m), made of plywood of 0.8 cm thick connected to a flat plate collector. The solar collector was 1.125 m^2 area (1.5 m x 0.75m). The absorber plate was made of light-gauge steel sheet of 0.7 mm thick, Frame of a wooden structure of (10 x 5) cm^2 cross sectional area. The bottom of the collector was insulated by a plywood of 0.8 cm thick. All air passages were made of steel sheets and insulated by 5 cm thick glasswool. The absorber plate of the collector was painted with a black paint. The collectors passages were 7.5 cm deep and also equipped with 2.5 cm air gap between the transparent glass cover and the absorber plate(stagnant air barrier) for reducing heat losses through the cover. The collector was oriented to the south and has a 4-bar mechanism to obtain the optimal inclination angle during the experiment. El-Rafey and El-Sherbiny (1988), reported the optimum tilt angles, insolation data base for estimating system performance in Egypt. Fig.(1) shows schematic diagram of the solar dryer with auxiliary heating system.



1-Air handling unit.
2-Solar collector.
3-Dryer bin.
4-Dryer door.
5-Chimney.
6-Supporting steel frame carrying the dryer bin.
7-Drying shelves.
8- θ = 30°.
9- Glass thermostat
10 - Contactor
11- Air heater
12- Ac source

Fig. (1) : Schematic diagram of the solar dryer with auxiliary heating system.

2. Measuring instrumentation

- Thermocouples :Temperatures were measured using chromel- alumel thermocouples, made in U.S.A (model 8528-40). Ten channel switch for the thermocouples were used.
- Solar intensity :The solar intensity was measured using a black and white Pyranometer constructed and calibrated by Ghanem (1989). The apparatus was recalibrated at the Solar Energy Department " National Research Center , El-Dokky Square " before being used in (1996). The output of the apparatus is in

millivolts using a digital multi-meter, manufactured in Japan, model no. 2000, of sensitivity 0.1 mV.

- Air velocity : The air velocity was measured using a standared pitot tube and inclined manometer as recommended by Tuve and Domholdt (1966).
- Samples were weighed using Sartorious electrical balance, made in Japan of accuracy 0.0001 g.
- Oven method was used for initial moisture content determination according to ASAE (1994), i.e. onion was dried for 24 h at 103 °C.
- Temperature controlling system : Glass thermostat and contactor were used for controlling the inlet air temperature for the auxiliary heating drying system.

3. Drying performance calculations :

The drying performance of all drying systems at any time period(ϕ) to ($\phi+\Delta\phi$) was calculated using the following expression (Thanavi and Pandae 1987):

$$P(\phi+\Delta\phi) = \frac{m_p * C_p * \Delta t + Ww * L}{A\int_{\phi}^{\phi+\Delta\phi} I_n d\phi} \qquad (6)$$

The specific heat of onion slices was taken 3.73 kJ /kg °C and the latent heat of vaporization of water was calculated at the drying air temperature according to A.S.A E .(1994) as follows :

$$L = 2502.535 - 2.3857(T - 273.16) \qquad (7)$$

where :

L : is the latent heat of vaporization of water at the drying air temperature , kJ/kg .

T : the drying air temperature , °K

The mass balance concept was used for the determination of the mass reduction of onion during a time period (ϕ) to " $\phi+\Delta\phi$ " :

$$m_p(\phi+\Delta\phi) = m_p(\phi)\,(1 - M_{wb}(\phi)) / (1 - M_{wb}(\phi+\Delta\phi)) \qquad (8)$$

$$W(\phi+\Delta\phi) = m_p(\phi+\Delta\phi) * M_{wb}(\phi+\Delta\phi) \qquad (10)$$

$$Ww = W(\phi) - W(\phi+\Delta\phi) \qquad (11)$$

where :

ϕ : is the local time , h ;

$\Delta\phi$: is the time period between two consecutive readings , it was 2 hours .

m_p: is the average mass of onion at a time period (ϕ) to ($\phi+\Delta\phi$),kg

W(ϕ): is the mass of water at any time ϕ, kg ;

Ww: is the water evaporated during a time period , (ϕ) to ($\phi+ \Delta\phi$) .

4. Drying coefficient evaluation :

The logarithmic model for drying as reported by Hall (1980), was used for evaluatiing the drying coefficient as follows :

$$\frac{M-M_e}{M_o-M_e} = e^{-K\phi} \qquad (12)$$

where M is the moisture content at any time during drying , (% dry basis) , M_o and M_e are the initial and equilibrium moisture contents , % dry basis , ϕ is the drying time in hours , K was assumed to be function of moisture content, air temperature , and airflow rates .

5. Costs of produced onion " LE/ton"

The cost analysis of onion was based on unit product basis .The total cost per unit weight of produced onion was estimated according to Awady et al . (1988).The total expected life is assumed five years . The cost new of the dryer with auxiliary heating system was 556 LE compared to 365 LE for the conventional solar dryer .

RESULTS AND DISCUSSIONS

In the present work two different drying systems for drying onion slices (4 mm thick) were tested , namely: forced convection solar dryer (conventional dryer) and forced convection solar dryer with an auxiliary heating system in which drying air temperature (60 ± 1°C) can be controlled. Table (1) includes solar intensity during the drying process , it also includes ambient air temperature ,relative humidity , and drying air temperature for the two drying systems tested . Onion slices were dried in thin-layer placed on dryer shelves .

Table(2) shows the moisture contents of the onion slices at different positions of the two drying systems. The moisture content at different positions of the traditional type solar dryer were distributed uniformly on the top middle and bottom shelves of the dryer . The standard deviation of the moisture distribution ranged between 0.005 to 0.028 . For the auxiliary type dryer , although , the drying process proceeds rapidly , there is little variations at the first drying stage between the moisture contents of the onion slices at the top , middle and bottom respectively. As the drying time proceeded the moisture variation between the different sites of the dryer decreased. The standard deviation between the moisture contents at different sites of dryer for the onion slices ranged from 0.365 at the first stage of drying to 0.077 at the end of the process . These variations may be due to non-homogeneous air distribution or due to high temperature and high drying rate .

Fig (1) shows the drying curves of the traditional type dryer and the auxiliary heated dryer .It is clear that onion slices that dried in the auxiliary heated dryer were dried within six to eight hours to an average moisture content of 7 % wet basis, while , in the traditional heated solar dryer the average moisture content was 44% within ten hours of drying .

The term drying performance was used because its value increased than unity . The increase of drying performance is due to the increase of moisture content that makes it similar to free water surface evaporation , and the increase of the output energy may be due to the high value of the latent heat of vaporizing water . Fig. (2). Shows that the performance of the auxiliary heated dryer is 5.9 compared to 1.51 for the traditional type solar dryer . As the drying time proceeded the performance of the traditional solar dryer gradually decreased slowly than that of auxiliary heated dryer . This could be interpreted by :

1. For the auxiliary heated dryer operating at drying air temperature of (60 °C ± 1) , onion slices were heated rapidly and facilitates evaporation of a large amount of water than that evaporated from slices in the traditional solar heated dryer at the same air flow rate (2.4 m^3/h) due to the small range of the drying air temperature i.e (from 28 –38 °C) .
2. As the drying time proceeded , there was a limited amount of water to be evaporated in long time spans , due to capillary characteristics of onion slices tissue which might interpret the lower performance of the auxiliary heated dryer than that of the traditional one.

The drying coefficient was also used for evaluating the drying speed of the onion slices .As the drying coefficient decreased the time required for drying the onion slices intcreased . It was found that the drying coefficient for the auxiliary heated dryer is 0.1546 compared to 0.0555 for the traditional type dryer .

Fig. (3) shows the production costs of drying one ton of onion slices for the auxiliary heated solar dryer compared to that of traditional one, although , the basic cost or investment of the traditional dryer was lower than that of the auxiliary one . The production costs of the auxiliary heated dryer was 361.16 LE/ton compared to 1185.69 LE/ton.

A cost-benefit analysis shows that the pay-back period for the auxiliary type solar dryer was 144 operating hours compared to 452.24 operating hours for the traditional type solar dryer.

SUMMARY AND CONCLUSION

To study the possibility of using a thin-layer solar dryer with an auxiliary heating system for drying onion slices .Two different drying systems for drying onion slices (4 mm thick), namely: forced convection solar dryer (traditional dryer) and forced convection solar dryer with an auxiliary heating system in which drying air temperature (60 ± 1°C) can be controlled ; were designed , constructed and tested on the roof of the Agricultural Engineering Department ; Al-Azhar University . Each of them has a dryer bin 0.2 m^3 (0.5x 0.5 x 0.80) with a capacity of 15 kg of wet onion slices. From the present study we can concluded that :

1. For the traditional type dryer the moisture contents on top , middle and bottom shelves are uniformly distributed with a standard deviation ranged from 0.028 at the first drying stage to 0.005 at the end of the drying process. For the auxiliary heated type dryer the moisture contents distribution have a little vriation on top , middle and bottom shelves with a standard deviation ranged from 0.365 at the first drying stage to 0.07 at the end of the drying process. This variation may be due to high drying air temperature (60 ± 1 °C) that increases the effective diffusivity depending on water contents of the onion slices and due to non-homogeneous distribution of the drying air .
2. Onion slices was dried to an average moisture content of 7% wet basis for the auxiliary heated dryer within six to eight hours compared to an average moisture content of 44 % within ten hours for the traditional type dryer .
3. The average drying performance of the auxiliary heated solar dryer was 1.37 compared to 0.96 for the traditional one.
4. The drying coefficient of the auxiliary heated dryer was 0.1546 compared to 0.0554 for the traditional one.
5. Production costs of drying one ton of the onion slices for the auxiliary type dryer was 361.69 LE/ton compared to 1185.69 LE/ton for the traditional type dryer.
6. A cost-benefit analysis shows that the pay-back period for the auxiliary type dryer was 144 operating hour compared to 452.24 operating hour for the traditional type dryer.
7. The small scale auxiliary drying system can be produced by farmers or craftsmen using simple tools and machines .

Table (1) : Solar inensity relative humidity ambient air and drying air temperatures of the two solar drying systems tested .

Local time	I	$T_{amb.}$	Td_1	Td_2	$RH_{amb.}$	RH1	RH_2
	kW/m^2	°C	°C	°C	%	%	%
8	0.258	28.1	28.9	60.5	100	99	43
10	0.662	32.2	35.2	61.3	79	77	50.5
12	0.994	37.7	39.6	61.3	46	44.9	38
14	0.92	38	42.9	61.9	32	31	27.2
16	0.589	34.1	41.1	61.9	44.5	42.4	27
18	0.055	32.1	35.4	61.7	50	49	40

Subscripts 1,2 amb.: means the traditinal solar dryer,auxiliary heating dryer and ambient air conditions respectively

Table (2):Moisture content distribution for onion slices(wet basis) at top(T) middle(M) and bottom(B) shelves of the two dryers tested and standared deviation.

Eapsed time	Traditinal solar heated dryer			S.D	Auxiliary solar heated dryer			S.D
	T1	M1	B1		T2	M2	B3	
0	0.85	0.85	0.85		0.85	0.85	0.85	
2	0.81	0.82	0.82	0.0051	0.68	0.64	0.4	0.265
4	0.74	0.75	0.75	0.0047	0.5	0.28	0.15	0.1748
6	0.62	0.63	0.61	0.0112	0.31	0.11	0.09	0.118
8	0.5	0.52	0.48	0.0200	0.21	0.04	0.008	0.1077
10	0.39	0.44	0.38	0.0280	0.15	0.006	0.06	0.077

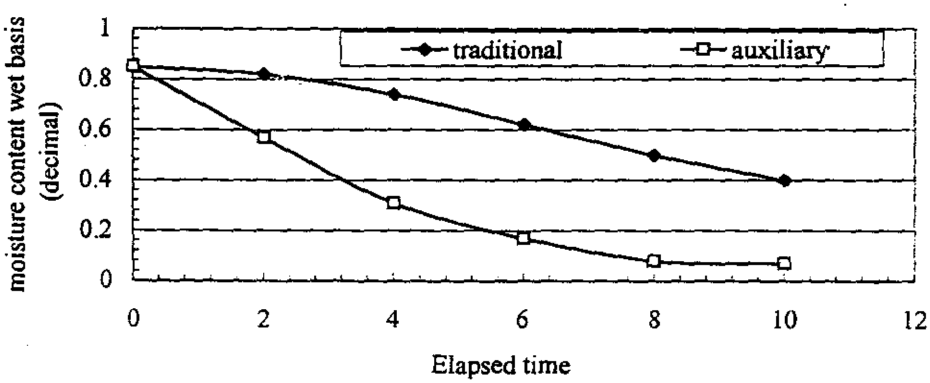


Fig.(1):Moisture content of both traditinal and auxiliary heated solar dryers as affected by drying time .

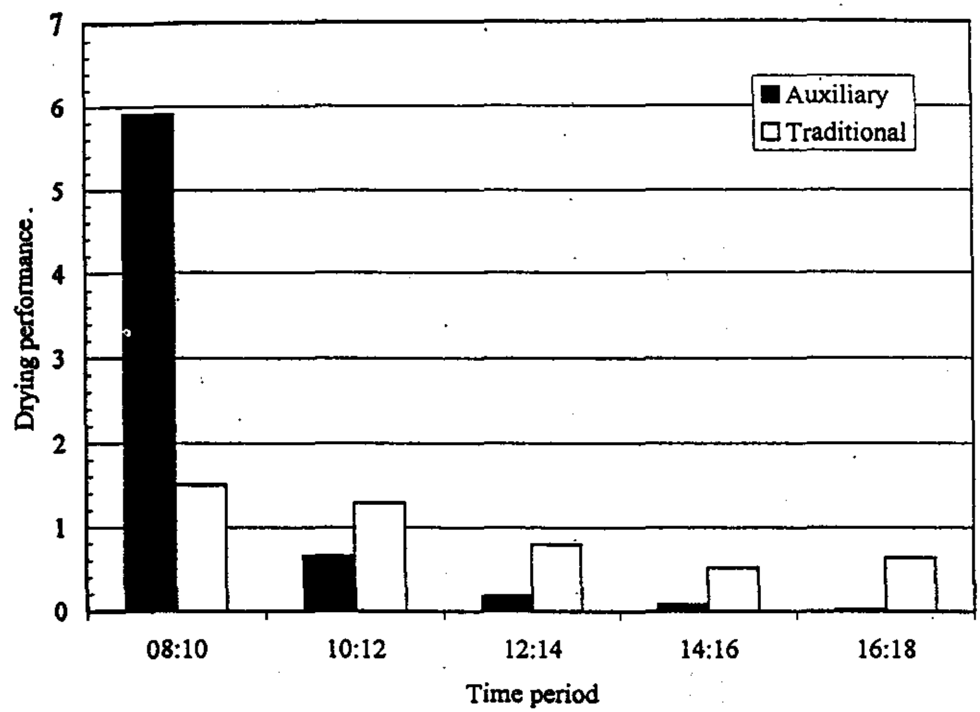


Fig.(2):Drying performance of both auxiliary and traditional solar dryers during the drying time periods .

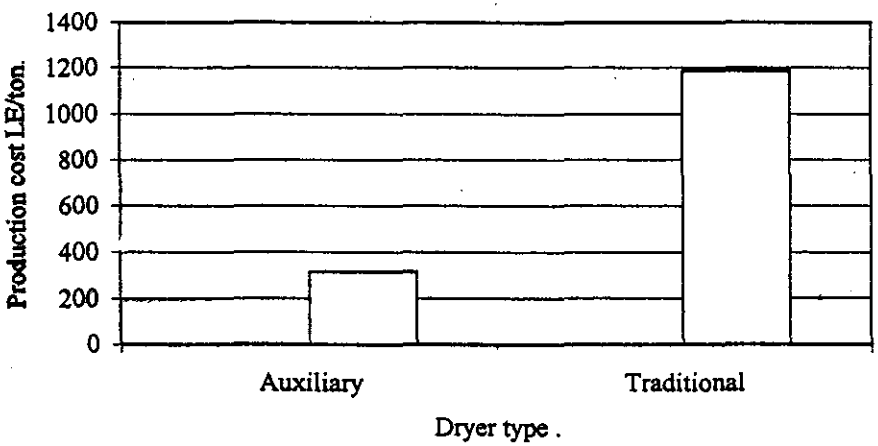


Fig.(3): Production costs (LE/ton) for both traditional and auxiliary heated dryers.

8. The system can be used successfully by farmers after a short introduction.
9. The auxiliary heated dryer can be also used for drying other crops such as grapes, red paper, figs, apricots, ……… etc.

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تجفيف البصل بإستخدام مجفف شمسي ذو نظام تسخين إضافي

د/طارق حسين مصطفى غانم

لدراسة إمكانية إستخدام مجفف شمسي ذو نظام تسخين إضافي لتجفيف شرائح البصل ، تم تصميم نظامين لتجفيف شرائح البصل (سمك ٤ مم) يعمل أحدهما بنظام تسخين شمسي فقط ويعمل الآخر بنظام تسخين شمسي وإضافي أيضا وكلاهمايعمل بالحمل الجبري.وقد كان حجم المجفف الداخلي ٠,٢ م٣ (٠,٥ م x ٠,٥ م x ٠,٨ م) ويسع ١٥ كيلوجراما من شرائح البصل الرطبة . ويمكننا مما سبق إستخلاص الأتي :

١. لقد كان توزيع الرطوبة متجانس على الأرفف العلوى و الأوسط والسفلي للمجفف الشمسي وبإنحراف قياسي ٠,٠٢٨ فى بداية التجفيف الى ٠,٠٠٥ فى نهاية التجفيف. بينما كان هناك اختلاف ضئيل فى توزيع الرطوبة في المجفف ذو النظام الاضافى للتسخين و بإنحراف قياسي ٠,٣٦٥ فى بداية مرحلة التجفيف الى ٠,٠٧ فى نهاية مرحلة التجفيف. ربما يعزى هذا الإختلاف الى عدم تجانس توزيع هواء التجفيف و الى إرتفاع درجة حرارة هواء التجفيف فى المجفف ذى النظام الإضافى مما يزيد من فعالية الإنتشارية تبعا للمحتوى الرطوبى لشرائح البصل .
٢. في نظام التجفيف ذى السخان الإضافى وصل متوسط الرطوبة لشرائج البصل المجفف ٧ % على أساس رطب خلال ٦-٨ ساعات بينما كان متوسط الرطوبة ٤٤ % فيمدة تصل الى عشر ساعات للمجفف الشمسي العادى.
٣. كان متوسط معدل الأداء للمجفف ذو النظام الإضافى ١,٣٧مقارنتا ب ٠,٩٦ فى النظام الآخر.
٤. كان معامل التجفيف للمجفف ذو النظام الإضافى ٠,١٥٤٦ مقارنتا ب ٠,٠٥٥ فى النظام الآخر.
٥. كانت تكاليف الإنتاجية اللازمة لتجفيف طن من البصل الرطب ٣١٦,١٦ جنيها مصريا للمجفف ذو النظام الإضافى مقارنتا ب ١١٨٥,٦٩ جنيها للمجفف الشمسي العادى.
٦. فى نظام التجفيف ذو السخان الإضافى يمكن إسترداد رأس المال خلال ١٤٤ ساعة تشغيل بينما يحتاج المجفف الشمسي الى ٤٥٢,٢٤ ساعة تشغيل لإسترداد رأس المال مع الأخذ فى الإعتبار النقص الحادث فى كتلة البصل المجفف.
٧. يمكن إنتاج المجفف ذو نظام التسخين الإضافى بواسطة المزارعين أو الحرفيين وبإستخدام أدوات بسيطة .
٨. يمكن إستخدام المجفف ذو السخان الإضافى لتجفيف العديد من المنتجات الزراعية كالتين والعنب والخوخ والمشمش ـــــــ الخ .

مدرس الهندسة الزراعية-كلية الزراعة-جامعة الأزهر