Passive Solar Drying of Loquat (*Eriobotrya japonica*) Fruit Slices

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ABSTRACT

A passive solar dryer was used to study the drying options of loquat (*Eriobotrya Japonica*) fruit slices, El-Sukary variety. The experimental work was carried out during May 2009 at El-Banger district, which located at the west of Alexandria, Alexandria, Egypt. The unpeeled loquat fruits were cut into flat slab to the required thicknesses that were 3, 5, and 7 mm depending on each required experiments. The moisture loss rates from loquat slices (3, 5 and 7 mm) were about 0.25, 0.32 and 0.42 g/hr, respectively. The results appeared that the solar intensity, drying temperature and sample thicknesses were the major variables affecting the drying rate. For evaluating the solar collector efficiency, the heat balance of solar collector was applied. The maximum result of solar collector efficiency was about 52%.

Keywords: passive, solar drying, loquat fruit, efficiency, chimney, drying chamber.

INTRODUCTION

The Loquat (*Eriobotrya Japonica*) is an edible fruit, which belongs to the *Rosacea* family (Badenes *et al*., 2000). Its reported composition fresh weight basses is: water 78%, carbohydrates 10.6%, fiber 10.2%, fat 0.5%, protein 0.4% and other components 0.3%. The world production of Loquat in 2006 is estimated at 550,000 t (Lin, 2007, Soler *et al*., 2007). Loquat grows well in Egypt, it is not widely known. It is mainly cultivated at home gardens. In 2007, the total area of loquat was about 290 Fadden, with production of 1273 ton. Cultivars grown include “El-Sukary, Advance, Premiere, and Tale Victoria”. Loquat fruits growing in clusters, oval, rounded or pear shaped, 1 to 2.5 inches long with a smooth or downy, yellow or orange, sometimes red-blushed skin.

Each fruit contains three to five large brown seeds. Generally, the loquat tree blooms in autumn with fruit ripping in early spring (April–May) (Morton, 1987).

Simal *et al*. (1994) reported that fruits such as loquat, apple, and vegetables like carrot are regarded as highly perishable food due to their high moisture content. Also, Atungulu *et al*. (2004) reported that, the fruits such as loquat contain a high percentage of their fresh weight as water. Accordingly, they exhibit relatively high metabolic activity compared to other plant-derived foods such as seeds. This metabolic activity continues after harvesting, thus making most fruits highly perishable commodities.

Loquat fruit is liked for its distinct sourness, sweetness and aroma and also because it is an early season fruit, however it has a short life after harvesting (Amoros *et al.*, 2008). A part from the fact, that it easily decays, it is also prone to nutritional and moisture losses (Ding *et al*., 2002). The use of cold stores may increase its shelf life but do not retain its initial quality (Ding *et al*., 1998a). To enhance the postharvest period of such perishable fruits, it is therefore vital to find other possible techniques.

Sun dryers essentially use the sun to heat the air, which flows over fruits in the dryer. This hot air has a low relative humidity so can, therefore remove large amounts of moisture from newly harvested crops. Agricultural and other products have been dried by the sun and wind in the open air for thousands of years. The purpose is to preserve food and/or crops which might otherwise spoil. Drying remove water and thus, prevents fermentation or the growth of molds. It also slows the chemical changes that take place naturally in foods, as when fruit ripens. A large portion of the world’s supply of dried fruits and vegetables continues to be sun dried in the open without technical aids (Szulmayer, 1971).

Some crops such as loquat, apple and grapes need to be protected from direct solar radiation to avoid undesirable discoloration in the resulting product. These crops should therefore be dried in indirect solar dryer (Muhlbauer 1986).

The present study attempts to fit a true model to the thin layer solar drying of loquat (*Eriobotrya* *japonica*) fruit slices, using an indirect solar dryer under metrological conditions of Banger El-Suker district, west of Alexandria, Alexandria, Egypt.

MATERIALS AND METHODS

Solar dryer setup

A passive solar dryer (mixed mode type, Fig. 1) was used in all experiments. The solar dryer consisted of a solar collector and a drying chamber. The solar collector consisted of a wooden box of 1.28 x 0.78 x 0.15 m. A black corrugated galvanized iron sheet of 1.28 x 0.7 m and 1 mm thickness was put inside the wooden box. The fibber isolation of 2 cm was put under the corrugated iron sheet and on the long sides of the wooden box to prevent heat losses through its thickness. A glass cover of 4 mm thickness was fixed over the wooden box to face the solar radiation. No electrical current input was used in the dryer, which made it more applicable in the rural areas of Egypt. The solar collector was tilted at an angle of 15^o from the horizontal, which was determined to be the optimum angle for the West of Alexandria location and May month. Collector system was oriented to face south direction.

The drying chamber was constructed with insulated wooden walls and with flat iron sheeting for the roofing and chimney. The drying chamber had a square cross section with 0.78 m sides. The drying tray was made with a wooden frame on all four sides and with wire mesh on the bottom to hold the samples. The heated air entered the drying chamber below the tray and flowed upwards through the samples leaving through the chimney. All the outside parts of the solar dryer were painted black to increase the absorbance of solar energy.

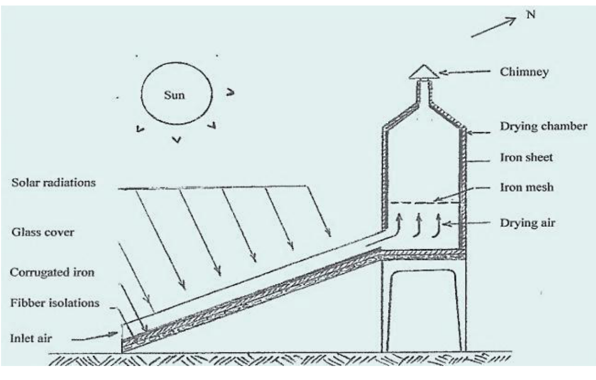

Fig. 1: Schematic drawing of a passive solar dryer

Samples preparation

Fresh loquat fruits, El-Sukary variety, yellow in colour were purchased locally. The average weight of each was selected to be 52 $\pm$4 g. The unpeeled fruits were cut into flat slabs to the required thicknesses that were 3, 5 and 7 mm, depending on each required experiments. The diameter of slab was in the range of 3.6 $\pm$1 cm. The skin was not removed to prevent moisture diffusion and evaporation in the radial dimension.

Drying experiments

The solar drying experiments were carried out during May 2009 at Banger El-Suker district, west of Alexandria, which is at latitude 31^oN and typical climatic conditions during the dry season are an ambient air temperature of 26-34 ^{o}C during the daylight, 55-65% relative humidity, 8.2±1.3 km/h wind velocity and 547-562 W/m^2 solar intensity. The loquat fruit slices were spread evenly on a drying tray, which was then placed on the middle shelf of the drying chamber. The loading density of the drying tray was 3.5 – 4.5 kg/m^2. Drying usually started at about 8:00 am and terminated at 6:00 pm, by closing the inlet air gate. The loaded tray was weighed every 15 min for the first two hours and then every 30 min until the end of the drying period. To weigh, drying tray was removed from the dryer for approximately 30 seconds. At the end of drying, a representative sample was taken for moisture content determination. Using the mean final moisture content and the final weight of dried loquat, the weight of dry solids was obtained.

The ambient and drying chamber bulb temperatures were recorded at each weighing time using a digital thermometer (VE 310) accurate to $\pm$ 0.1 ^{o}C. The drying chamber temperature was measured at the center of the chamber and directly below the drying tray and was considered as the temperature of drying air. Solar intensity and wind velocity were measured using MC11 digital pyrometer (with accuracy of ± 10 w/m^2) and Vane type digital anemometer (with accuracy of ± 0.1 m/s), respectively.

Theoretical heat balance of the solar collector

The next version was built depending on Duffie & Beckman (1991);

In order to define the energy balance of the solar collector, the following equation was used:

$Q_u = A_c F_R [S - U_L (T_h - T_a)]$ (W)……............. (1)

Where; A_c is the collector area (m^2), F_R is the heat removal factor (dimensionless), S is the absorbed solar radiation/unit area (w/m^2), U_L is the collector overall heat loss coefficient ($w/m^2.^ok$), T_h is the hot air temperature inside the collector and T_a is the ambient air temperature.

Absorbed solar radiation (S)

$S = I_b R_b (\tau\alpha)_b + I_b (\tau\alpha)_d (1 + \cos\beta)/2 + \rho_g (I_b + I_d)$ $(\tau\alpha)_g (1 - \cos b)/2$ (W) ………..……………..…(2)

Absorbed solar radiation consists of three different radiations, index b means beam radiation (direct), index d means diffuse radiation, and index g means ground reflected radiations.

Where, I is the irradiation (w/m^2), R_b is the ratio of beam radiation on the tilted surface to that on horizontal surface (dimensionless), τ is the transmittance (dimensionless), α is the absorbance (dimensionless), $(1+\cos\beta)/2$ and $(1-\cos\beta)/2$ are view factors from the collector to the sky and from the collector to the ground, respectively, ρ_g is the ground reflectance (dimensionless), and β is the tilt angle of solar air collector.

Heat removal factor (F_R)

Heat removal factor related the actual useful energy gain of a collector to the useful gain if the whole collector surface was at the air inlet temperature.

In order to calculate the heat removal factor, some partial equations need to be solved.

$F_R = F'. F''$ ……………………..…..………. (3)

Where:

F' is the collector efficiency factor

F'' is the collector flow factor.

$F' = 1 + [U_L / h + (1/h + 1/h_r)^{-1}]$ ……………..……(4)

Where, h is the convection heat transfer coefficient of air ($w/m^2.^ok$), and it can be calculated from;

$h = Nu . (k/D_h)$ ($w/m^2.^ok$)

$D_h = \{4 \text{ (flow rate) / witted perimeter}\}$ (m)

$Nu = 0.0158 Re^{0.8}$ (dimensionless)

$Re = m D_h / A_f \mu$ (dimensionless)

Where, Nu is the Nusselt number, D_h is the hydraulic diameter (m), k is the thermal conductivity ($w/m.^ok$), Re is the Renold's number, m is the air flow rate (kg/s), $A_f = A_c$, and m is the air dynamic viscosity (kg/s.m) .

$F'' = (\dot{m} Cp/A_c U_L F') [1 - e^{-(Ac U_L F'/m Cp)}]$……............ (5)

$h_r = 4 s T_h^3 / (1/e_g + 1/e_p - 1)$ ($w/m^{2o}k$) …..……...... (6)

Where, $\dot{m}$ is air flow rate (kg/s), C_p is air specific heat ($kJ/kg.^ok$), h_r is the radiation heat transfer coefficient ($w/m^2.^ok$), σ is Stefan Boltzman constant (56.7×10^{-9} $w/m^2.^ok^4$). ε_g and ε_p are the emittance of glass and plat, respectively.

Overall collector heat loss coefficient (U_L)

$U_L = U_t + U_b + U_e$ ($w/m^2.^ok$) ……………....... (7)

Where, U_t is the top loss coefficient ($w/m^2.^ok$), U_b is the energy loss through the bottom of the collector ($w/m^2.^ok$), and U_e is the edge thermal losses ($w/m^2.^ok$).

$$U_t = \left\{ \frac{N}{\frac{C}{T_{p,m}}\left[\frac{(T_{p,m}-T_a)}{(N+f)}\right]^e} + \frac{1}{h_w} \right\}^{-1} + \frac{\sigma (T_{p,m}+T_a)(T_{p,m}^2+T_a^2)}{(\varepsilon_p + 0.00591 N h_w)^{-1} + \frac{(2N + f - 1 + 0.133\,\varepsilon_p)}{\varepsilon_g} - N} \quad \ldots\ldots (8)$$

Where, N is the number of glass covers,

$f = 1 + 0.089 h_w - (0.1166 h_w \varepsilon_p)(1 + 0.07866N)$,

$C = 520 (1 - 0.000051 \beta^2)$ for $0^o < b70 > {}^o$,

$e = 0.48 (1 - 100/ T_{p,m})$

β is the collector tilt angle (degrees)

$T_{p,m}$ is the mean plate temperature (^ok),

h_w is the wind heat transfer coefficient ($w/m^2.^ok$),

$h_w = 8.6 V^{0.6}/L^{0.4}$ ($w/m^2.^ok$)

V is the wind speed (m/s),

L is cubic root of the drying chamber volume (m).

$U_b = k/L$ ($w/m^2.^ok$)……….......…..……………(9)

Where, k is the insulation thermal conductivity ($w/m.^ok$), and L is the thickness of insulation (m).

$U_e = (UA)_{edge} / Ac$ ($w/m^2.^ok$) ……….............(10)

Solar collector efficiency (η),

Solar collector efficiency defined as the ratio of the useful energy gain over some specified time period to the incident solar energy over the same time period.

$$\eta = \frac{\int Q_u\, d_t}{Ac \int I_t\, d_t} \quad \ldots\ldots (11)$$

A hour collector efficiency and the day-long collector efficiency were defined from the following formulas (12 & 13), respectively;

$$\eta = \frac{Q_u}{Ac\ I_t} \times 100 \quad \text{……...………..……..…….…..…} \ (12)$$

$$\eta_{day} = \frac{\sum Q_u}{Ac \sum I_t} \times 100 \quad \text{……...…………..…..….……} \ (13)$$

Where, I_t is the solar radiation intensity (w/m^2).

RESULTS AND DISCUSSIONS

Loquat moisture content vs. solar intensity, drying chamber temperature:

The moisture content of loquat versus time plot for one representative solar drying curve is shown in Fig.(2). The drying chamber temperature and solar radiation for the drying period are also shown. It was clear that moisture content of loquat slice was quite low during the first hour as the drying chamber warmed up. The maximum drying occurred between 2.5 and 4 hours (from 10:30 am to 1:00 pm), and corresponded to the drying chamber reaching its maximum temperature on nearly 77 ^oC during the hottest part of the day, and the solar intensity was about 640 w/m^2. After about 5 hours, drying rate began to decrease markedly but the drying chamber temperature remained high until at least 5.5 hours. At the first day of drying, the loquat slices are clearly entering its falling rate, but the moisture content still high, so that the second day of drying is essential. The final moisture content of loquat fruit slices was about 12.4% w.b for the three slices thickness but 3mm thickness was dried at total time of 30 hours (actual drying period 17 hours). Whereas, 5 mm and 7 mm thickness need 33 and 35 total hours (actual drying period 20 and 22 hr) for drying, respectively. So that, the solar intensity, drying temperature and sample thickness and initial moisture content were the major variables affecting the drying rate of loquat fruit slices.

Solar drying rate vs. loquat thickness:

Figure (3) appears moisture loss rate (g water/hr) and drying rate versus loquat thickness. It's indicted that, increasing of moisture loss rate as increasing of loquat thickness. Losing rates of water quantity (M_{loss}) from loquat slices (3, 5 and 7 mm) were about 0.25, 0.32 and 0.42 g/h, respectively. The curve trend increased until critical thickness appear, and more thicknesses must be tested. On the other hand, it was clear that decreasing of drying rate (Dr) as loquat thickness decreases.

The second order equation was resulted as the best fit of data, using Excel-2010 software. The resulted form is:

$$M_{Loss} = 0.0046\ \delta^2 + 0.0901\ \delta \qquad (R^2 = 0.98)\ldots(14)$$

$$Dr = 0.0369\ \delta^2 - 0.6211\delta + 5.9917 \quad (R^2 = 1)..\ (15)$$

Where, M_{Loss} is the moisture loss rate in g water per hour, Dr is the drying rate in percentage of w.b per hour and δ is the loquat thickness in mm.

Ambient and outlet collector temperature

Figure (4) shows the ambient air temperature and collector outlet temperature data as a function of time of the day. It was clear that, the ambient temperature increases during daytime, with a maximum value reached near noon time, with the maximum value of solar intensity. Ambient air passes through a solar collector which raises the air temperature. Therefore, the collector outlet temperature, which in turn is the inlet dryer temperature (To) is

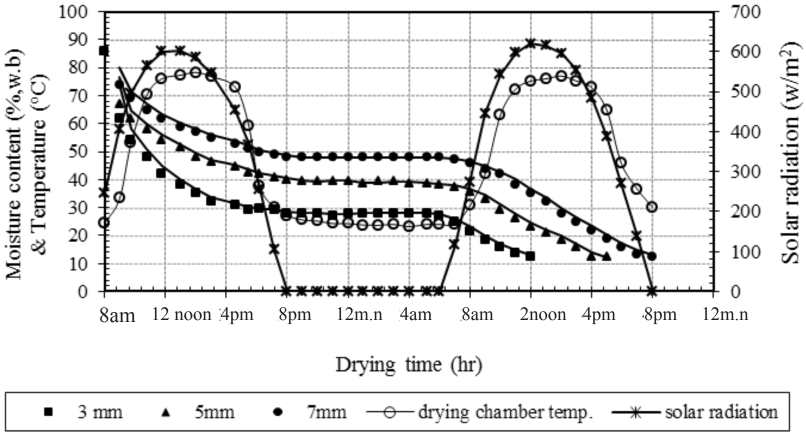

Fig. 2: Behavior curves of moisture content of loquat slices, drying chamber temperature and solar intensity during the drying time

8am 12noon 4pm 8pm 12m.n 4am 8am 2noon 4pm

8pm

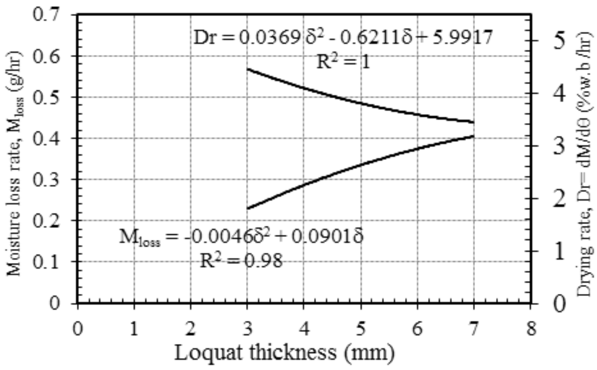

Fig. 3: Moisture loss rate and drying rate vs. Loquat thickness

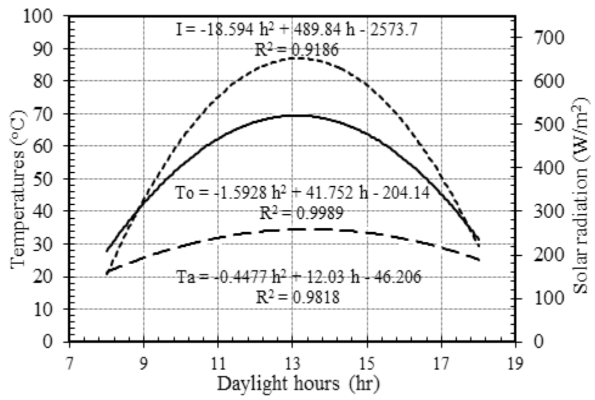

Fig. 4: Solar radiation, ambient and outlet collector temperatures during daylght hours

also a time-varying function. This time function is the boundary condition of the model. The collector outlet temperature has been correlated as a function of time with a second-order polynomial in order to simulate the boundary condition for dryer model. The result of such correlation is:

$To = - 204.14 + 41.752\ h - 1.5928\ h^2$ ………. (16)

Where h is the hour of the day as continues numbers.

Effect of absorbed solar radiation on temperature difference:

Figure (5) shows the effect of absorbed solar radiation (S) in the collector on temperature difference (ΔT) between hot air inside the collector and ambient temperature (To-Ta). It was obvious that, as absorbed solar radiation increases the temperature difference increased. This relationship was developed to best fit using Excel-2010 software, and the following formula was resulted;

$\Delta T = 2.1554 + 0.0223\ S$ ($R^2 = 0.896$) ……..(17)

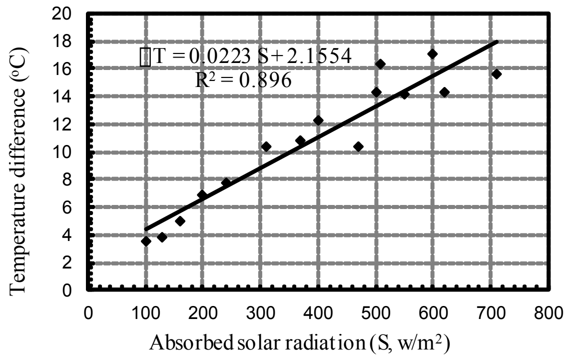

Fig. 5: Effect of absorbed radiation on temperature difference

Effect of solar radiation on collector efficiency

In illustration Fig. (6), in general that, there was an increasing in collector efficiency (η) with increasing solar radiation intensity (I).

An equation developed using Excel-2010 software, which has a formula of the second order equation as following;

$\eta = 14.239 + 0.0043I + 7E\text{-}05I^2$ ($R^2 = 0.96$)…..(18)

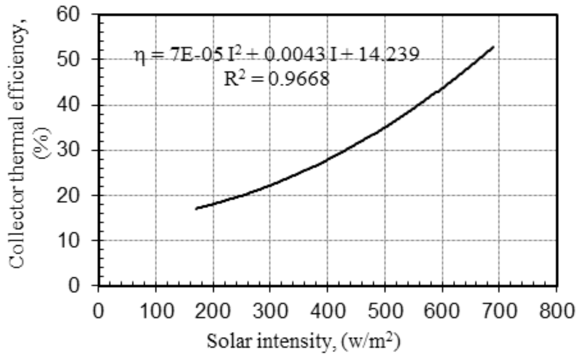

Fig. 6: Effect of solar intensity on collector efficiency

CONCLUSION

- The mean effective drying chamber temperature, solar radiation intensity and sample thickness were the main factors that affected the solar drying of loquat fruit slices. This agreed well with those reported by Diamante & Munro (1991).

- The drying chamber temperature increased rapidly during the first four hours and decreased slowly during the last 2 hours but was relatively constant between four to seven hours from the beginning of the solar time.

- The drying rate trend increased until critical thickness appear, as indicated by the resulted equation, so we recommended that, more thicknesses of loquat fruit must be experimented.

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التجفيف الشمسي السلبي لشرائح فاكهة الاسكدينا (البشملة)

رجب إسماعيل مراد

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تناولت هذه الدراسة الاستخدام غير المباشر (السلبي) للطاقة الشمسية لتجفيف شرائح فاكهة الاسكدينا (البشملة – صنف السكري) (*Eriobotrya Japonica*)، من خلال إعداد مجفف يعمل بالطاقة الشمسية يتكون من مجمع للطاقة الشمسية وغرفة تجفيف مزودة بمخرج علوي لخروج الهواء (دون وجود مصدر تيار كهربي) بعد مروره علي المجمع الشمسي لتسخينه ثم مروره علي شرائح فاكهة الاسكدينا (٣مم ، ٥مم و٧ مم) لتقليل محتواها الرطوبي والدخول في مرحلة التجفيف.

أجريت التجارب بقرية البنجر الواقعة بغرب مدينة الاسكندرية، وذلك خلال شهر مايو ٢٠٠٩، حيث كانت الظروف المناخية بالمنطقة كالتالي: متوسط درجة الحرارة ٢٦– ٣٤°م ، متوسط شدة الاشعاع الشمسي خلال التجارب تراوح مابين ٥٤٧–٥٦٢ وات/م٢، الرطوبة النسبية في حدود ٥٥ – ٦٥٪ و سرعة الرياح تعادل ٨,٢ ±١,٣ كم/ساعة.

أوضحت التجارب أن شدة الاشعاع الشمسي، سمك العينات المستخدمة في التجفيف و درجة حرارة غرفة التجفيف هي العوامل الأكثر تأثيراعلي معدل التجفيف. حيث جففت العينات ذات السمك (٣، ٥، ٧مم) خلال (١٧، ٢٠، ٢٢ ساعة تجفيف حقيقية) علي الترتيب، ليصل المحتوى الرطوبي للشرائح المنتجة ١٢,٤٪، ليكون الفقد الرطوبي (٠,٢٥، ٠,٣٢، ٠,٤٢ جرام ماء/ساعة) لسمك العينات الثلاث علي الترتيب.

ولحساب كفاءة أداء المجمع الشمسي، أجريت حسابات الإتزان الحراري للمجمع الشمسي، مع توضيح العلاقة بين شدة الاشعاع الشمسي والكفاءة الحرارية للمجمع الشمسي، حيث أظهرت النتائج أن القيمة القصوي لكفاءة أداء المجمع الشمسي تعادل ٥٢٪.