Various Air Solar Collector Systems For Drying Lemon-Grass (*Cymbopogon citratus*)

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ABSTRACT

Different systems of air solar collectors were used with an active solar dryer to study the drying options of a thin layer of lemon-grass (*Cymbopogon citratus*). Three air solar collector systems were tested by outlet air temperature, absorbed energy, gained energy and thermal efficiency. The results indicated that, the additional collector plate to the most common air solar collector and the additional air flow passing upper and lower the absorbed plate, increased outlet air temperature by 18.5%, followed by increasing the energy gained by 41%, and increasing of the thermal efficiency of the air solar collector by 69%. That system increased the drying rate of lemon-grass by 37.5%.

Keywords: active solar drying, lemon grass, thermal efficiency, drying chamber.

INTRODUCTION

Several configurations of solar air heater have been developed. Various designs, with different shapes and dimensions of the air flow passage in plate type solar air collectors were tested (Hollands & Shewan, 1981, Yeh *et al.*, 2000). The double-flow type solar air collector have been introduced for increasing the heat transfer area, leading to improved thermal performance (Yeh *et al.*, 1999). This increases the thermal energy between the absorber plate and the air, which clearly improves the thermal performances of the solar collectors with obstacles arranged into the air channel duct. These obstacles allow a good distribution of the fluid flow (Zaid *et al.*, 1999 and Moummi *et al.*, 2004). Since 1950, many researchers have studied this type of thermal device and designed models for different solar air heater collectors configurations, as downward type and upward type air heaters, with or without cover glass, flat plates solar collectors with energy storage unit (Jain and Jain, 2004 and Jain, 2007), collectors with multi flow channels or multi pass (Forson *et al.*, 2003) among others.

Sun dryers essentially use the sun to heat the air, which flows over the commodities in the dryer. Hot air has a low relative humidity; therefore remove large amounts of moisture from newly harvested crops. Many agricultural products have been sun dried in 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. A large portion of the world's supply of dried fruits and vegetables continues to be sun dried in the open air without technical aids (Szulmayer, 1971).

Some crops 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).

Moustafa *et al.* (2009) studied the effect of drying air temperature and air humidity on the drying characteristics of lemon grass and developed a model to estimate the drying curves.

Lemon-Grass (Fig. 1) is native to Malaysia, and is an important ingredient in Southeast Asian cooking. It is a tender perennial with a mild lemony fragrance and a lemon-citrus type taste. The stalks are too tough to eat, but they can be chopped and pounded to add flavour to fish or poultry sauces, and stir fry. Lemon-grass has long, thin, sharp grass-like gray-green leaves, and a scallion-like base. It grows to up to 6 feets under ideal conditions in the tropics, and to about 3 feets in more northerly climates, so using it as a mid to back of the bor-

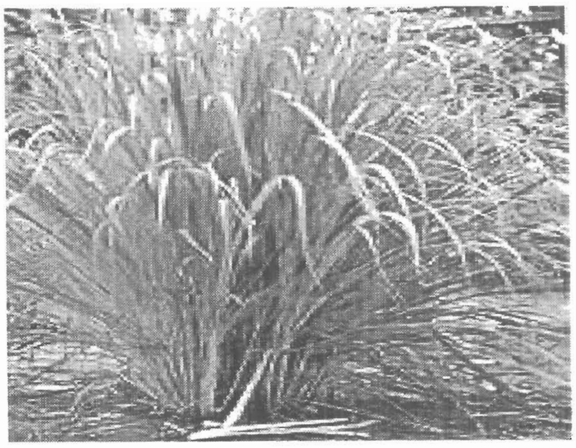

Fig. 1: Photographic of lemon-grass (*Cymbopogon citratus*)

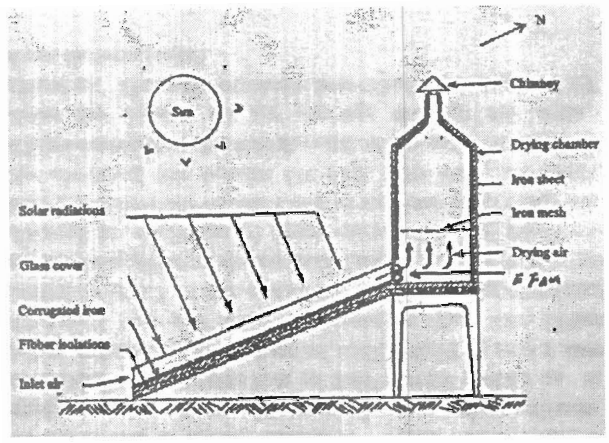

Fig. 2: Schematic drawing of an active solar dryer

der plant. It makes a nice contrasting backdrop for most any shorter annual or perennial flower or herb (Gardens Ablaze, 2012).

Shadab *et al*., (1992) reported that, lemon grass is native to India and tropical Asia. It is widely used as a herb in Asian cuisine. It has a subtle citrus flavour and can be dried and powdered, or used fresh. Lemon-grass is commonly used in teas, soups, and curries. It is also suitable for poultry, fish, beef, and seafood. It is often used as a tea in African countries such as Togo and the Democratic Republic of the Congo and Latin American countries such as Mexico. Lemon grass oil is used as a pesticide and a preservative.

The present study aims to evaluate the thermal performance of different air solar collector systems, with various air flow directions and their effect on drying a thin layer of lemon grass (*Cymbopogon citratus*), as a test crop for the drying process.

MATERIALS AND METHODS

Systems design:

An active solar dryer (Fig.2) was used in all experiments. The solar dryer consisted of a solar collector and a drying chamber. Three solar collector systems were used. In general, the solar collector consisted of a wooden box of 2.50 x 0.68 x 0.12 m. A black galvanized iron sheet of 2.50 x 0.60 m with 1 mm thickness was put inside the wooden box. A fibber isolation of 0.2 m was placed under the black iron sheet and on the long sides of the wooden box to prevent heat loss. A glass cover of 3 mm thickness was fixed over the wooden box to face the solar radiation. An electrical fan (model OC-15R, 220 Volt, 50 Hertz, China made) was fixed at the end of the solar collector to drive the heated air to pass through the drying chamber. The solar collector was tilted at an angle of 15° from the horizontal, as a suitable experimental condition for West-Alexandria location in June 2011.

The previous collector was named system (I). The solar collector system (I) was modified with additional black iron sheet suspended in the middle of the wooden box and the air flow was directed to passed under the black iron sheet. That represents system (II). The third solar collector system (III), is similar to system (II), but the air flow passes above and under the black iron sheet (Fig.3).

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 0.68 m sides. The drying tray was made from a wooden frame on allover the four sides fixed 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 and leaving through the chimney. All the outside parts of the solar dryer were painted black to increase the absorbance of solar energy.

Experimental work:

The solar drying experiments were carried out during June 2011 at Banger El-Suker District, west of Alexandria, which is at latitude 31°N and typical climatic conditions during the dry period are: ambient air temperature of 24-32°C during the daylight, 55-75% relative humidity, 5.2±1.1 km/h wind velocity and 513-542 W/m² solar intensity. Fresh

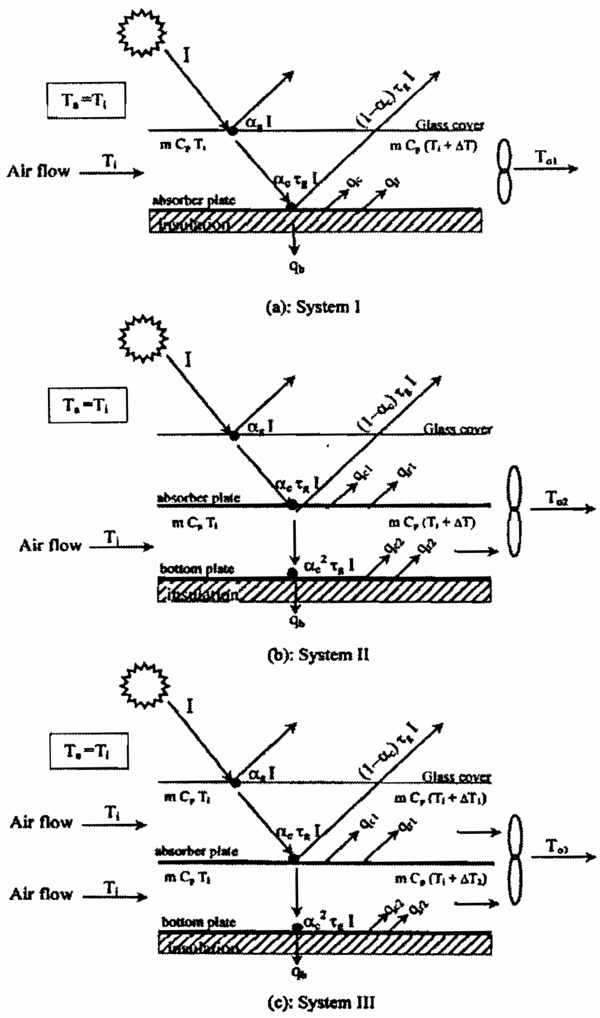

Fig. 3: Schematics drawing of thermal behavior of air solar collector systems

lemon grass was collected from a private farm at Abees district, east of Alexandria. The initial moisture content of lemon grass was about 293.7 (d.b). The lemon grass was 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 1.5 kg/m^2. An electrical regulator was connected to an electrical fan to adjust the air flow rate at 0.046 kg/min for lemon-grass drying, and for the three air solar collector systems. Drying usually started at about 7:00 am and terminated at 7:00 pm. The loaded tray was weighed every 60 minutes for the first two hours and then every 120 minutes until the end of the drying period. Weighting involved removing the drying tray from the dryer for approximately 30 seconds. At the end of drying, a representative sample was taken for moisture content determination. The moisture content was reported as percentage. The weight of dry solids was then obtained.

The ambient and drying chamber bulb temperatures were recorded at each weighting time by using a digital thermometer (VE 310), accurate to $\pm$ 0.1°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 $\pm$ 10 w/m^2) and Vane type digital anemometer (with accuracy of $\pm$ 0.1 m/s), respectively.

The thermal behavior inside the air solar collector systems:

At an instant of time, the collector produces an amount of heat equal to (q) per unit area of the cover. The average temperature of the absorber collector is (T_c) and the average temperature of the glass cover and the ambient are (T_g) and (T_a), respectively. The solar system receives solar radiation (I) at a rate of watt per unit area of the cover. An amount ($\alpha_g I$) of this incident radiation is absorbed in the glass cover, an amount ($\tau_g I$) is transmitted through the cover, and the rest is reflected by the cover to the ambient. The transmitted radiation from the cover ($\tau_g I$) is divided into two parts: one is absorbed by the collector in the system, ($\alpha_c \tau_g I$) and the other is reflected by the collector surface $\{(1-\alpha_c)\tau_g I\}$. The latter is assumed to be transmitted directly to the ambient through the cover without any reflection or absorption at the cover. The collector in the system absorbs heat at a rate of ($a_c t_g I$), and also loses heat to the cover by convection (q_c) and radiation (q_r). The collector system loses heat to the ground through its base and its edges at a rate of (q_b). A part equal to (q_{gain}) of the heat absorbed by the air flow in the collector system is used to increase the feed temperature to that of the base (Fig. 3). The values q_c, q_r, q_b, and q_{gain} are per unit area of the cover. The effect of the heat absorbed or lost by the air is certain to increase or decrease the air flow temperature. The collector system cover receives (q_c) and (q_r) from the collector in the system, and loses heat to the ambient by combined convection and radiation at rate (q_{ga}). To improve the useful energy and increase the gained energy, an additional absorbed plate was added to the previous system (it is suspended in the middle of the solar collector as shown in Fig. 3 b and c). The additional absorbed plate received a quantity of heat equal ($\alpha_c^2\tau_g I$), those additional energy increased in energy gained for air flow, where the air flow pass above and under the absorbed plates. So, there is an expected improving rate in drying rate which will appear during the drying operation.

The theoretical model employed for the study of solar collector that operates in unsteady state is made using a thermal energy balance (Hikmet, 2008):

Accumulated energy + Energy gain =

Absorbed energy – Lost energy ....(1)

For each term of Eq. 1 the following expressions are formulated:

Accumulated energy rate= $M_c\, C_p\, (dT_c/dt)$ ....(2)

Energy gain (q_{gain})*rate=* $m\, C_p\, (T_o - T_i)$ ....(3)

Absorbed energy (q_s) *rate=* $A_c\, I\, (ta)$ ....(4)

Lost energy rate= $A_c\, U_c\, (T_c - T_a)$ .... (5)

From Eq.1 to Eq. 5;

$M_c\, C_p\, (dT_c/dt) + m\, C_p\, (T_o - T_i) =$

$A_c\, I\, (\tau_g \alpha_c) - A_c\, U_c\, (T_c - T_a)$ ....(6)

Where, A_c is the collector surface in m^2, M_c is the collector mass in kg, m is the mass flow rate in kg/m, C_p is the specific heat of air at constant pressure in kJ/kg K, T_i and T_o are inlet and outlet air temperatures in °C, respectively, and a_g, a_c and t_g are glass and collector absorptance and glass transmittance, respectively. Besides the hourly environmental parameters *I*, T_a, and *Rh*, the following physical properties are used as input data; $Ac = 1.5$ m^2, $\alpha_c=1$, $\alpha_g=0.05$ and $\tau_g=0.90$ (Sartori, 1987)

The optical yield ($a_c\, t_g$) and the energy lose coefficient (Uc) are the parameters that characterize the behavior of the solar collector. Note that ($\alpha_c\, \tau_g$) represents the fraction of the solar radiation absorbed by the plate and depends mainly on transmittance of the transparent cover and on the absorptance of the plate.

The energy loss coefficient includes the losses by the upper cover, the laterals, and the bottom of the collector. The upper cover losses prevail over the others, depending to a large extent on the temperature and emissivity of the absorbent bed, and besides, on the convective effect of the wind on the upper cover.

The thermal efficiency of the solar collector (h) is defined as the ratio between the energy gain (q_{gain}) and the solar radiation incident on the collector plate ($a_c t_g\, I$):

For system I;

$\eta = m\, C_p\, (T_o - T_i)/\, A_c\, I\, (\alpha_c\, \tau_g)$ .... (7)

Where, there is an additional absorber black iron sheet suspended on the middle of collector box as shown in Figures 3 (b and c), the other a_c would be added, so that, the thermal efficiency of solar collector systems (II and III) are:

$\eta = m\, C_p\, (T_o - T_i)/\, A_c\, I\, (\alpha_c^2\tau_g)$ .... (8)

RESULTS AND DISCUSSIONS

Outlet collector temperature:

Figure 4 shows the hourly variation of inlet (ambient temperature) and outlet solar collector temperatures affected by solar radiation intensity [X-axis begin from number 6 (6 am) and ended at number 20 (8 pm)]. It is clear that, increasing of inlet and outlet air temperatures as solar radiation intensity increases. It shows that, the inlet air temperature (T_i=T_a) increases to a maximum value of 26.5 °C between 12 and 1 pm before it starts to decrease in the afternoon. The outlet (T_{o1}, T_{o2} and T_{o3}) air temperature increases to a peak value of 57.5, 65.4 and 68.3°C for air solar collector systems I, II and III, respectively, at 1:15 pm at the maximum solar intensity (555.3W/m^2) and then decreases as solar radiation intensity drops to lower values later during the daylight.

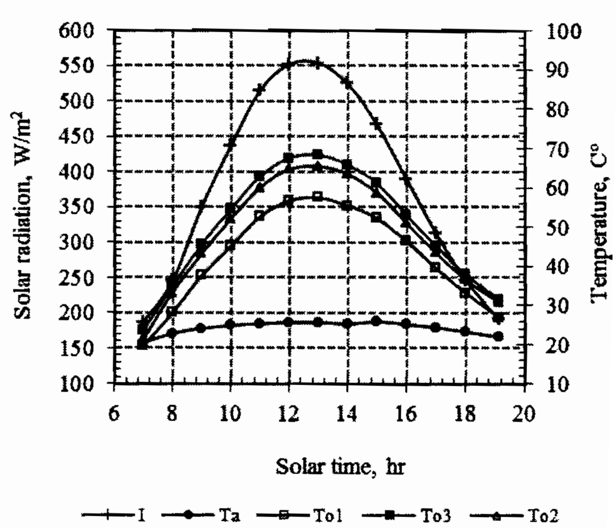

Fig. 4: The hourly variation of solar radiation, inlet and outlet solar collector temperature with various air solar collector systems.

Air relative humidity:

The illustration presented in Fig.(5) shows the relationship between the outlet temperature from the collector systems and the outlet relative humidity from the drying chamber during the solar time. This indicates that, the outlet air relative humidity from the drying chamber increases with an outlet temperature increase. This explains that, as the outlet temperature increases the moisture removal from lemon-grass increases with relative humidity increase until an equilibrium moisture content (13.2% d.b.) appears. The results show the success of using air solar collector system III over that of both of systems II and I. The equilibrium moisture content occurred at 8, 9 and 11.5 hr., respectively from the beginning of the drying operation. (Note: the air relative humidity at the inlet of the drying chamber of the three systems was 30±5.3%).

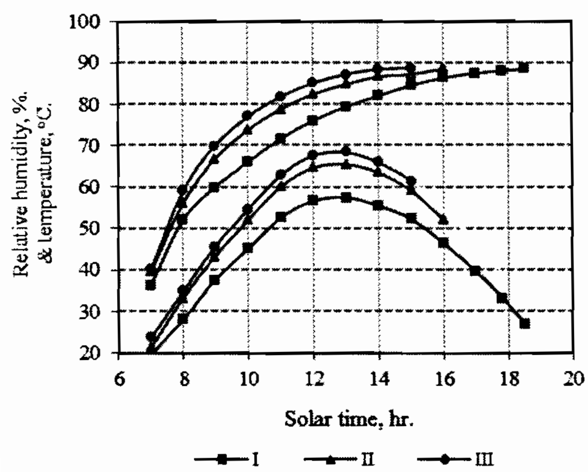

Fig. 5: The relationship between the outlet temperature from collector systems and outlet air relative humidity from the drying chamber during the solar time

Useful heats:

The absorbed energy (qs) and gained energy (qus1, qus2 and qus3) with different air solar collectors are illustrated in Fig. (6). It is clear that there is an increase of absorbed energy and gained energy as solar intensity increases (Fig.4). The gained energy of air solar collector system III has upper values followed by system II and system I. This explains, the success of air solar collector system III on outlet temperature and drying rate.

Solar collector thermal efficiency:

Figure 7 shows the thermal efficiency of air solar collector system as calculated by equations 7

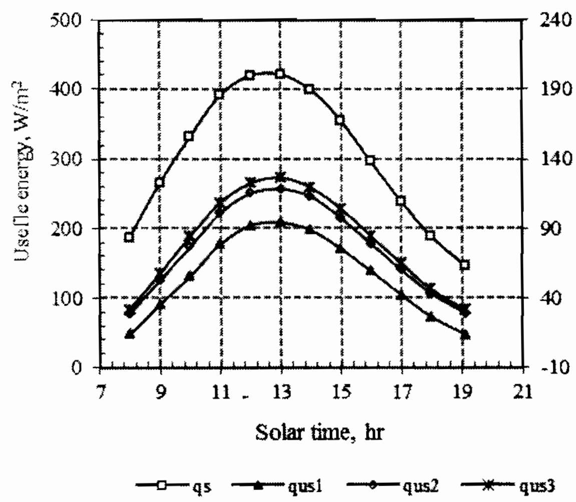

Fig. 6: Behavior of absorbed and gained energies at different air solar collector systems during solar time.

and 8 during the solar time. The thermal efficiency of the air solar collector systems I, II and III increases to a peak values of 28.4, 40.2 and 42.6% and then decrease to 16, 28.1 and 31.1% respectively, as solar time increases to 7:00 pm. It is clear that, the success of thermal efficiencies of air solar collector system III over systems II and I during the solar time. The additional absorber plate and air flows upper and under the absorber plates caused in high values of outlet temperature (T_{o2} and T_{o3}) followed by increase of energy gained for air flow of system III and II, (as shown at Fig.4 and Fig.6), followed by increase in thermal efficiencies for system III and II, as shown in (Fig. 7).

Solar drying curve:

Figure 8 shows the lemon grass moisture content values during the solar time of drying opera-

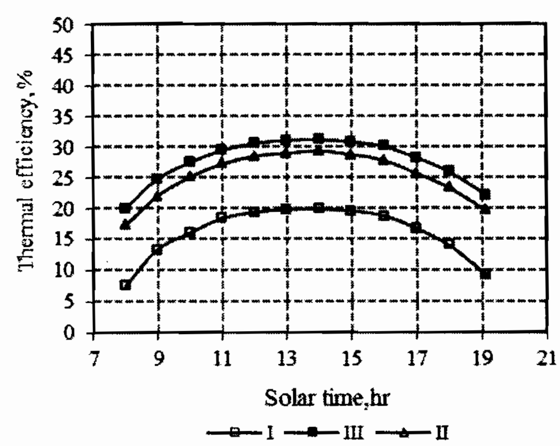

Fig. 7: The thermal efficiency of the air solar collector systems during the solar time.

tion by using different air solar collector systems. It is clear that, the moisture content of lemon-grass reached to its equilibrium (13.2% d.b.) after drying time of 8, 9 and 11.5 hr., for air solar collector system III, II and I, respectively. Drying rate is the best for system III followed by system II and by system I that is due to the increase in energy gained for systems III and system II, which is added by the additional absorbed plate and upper and lower air flow (Fig. 6).

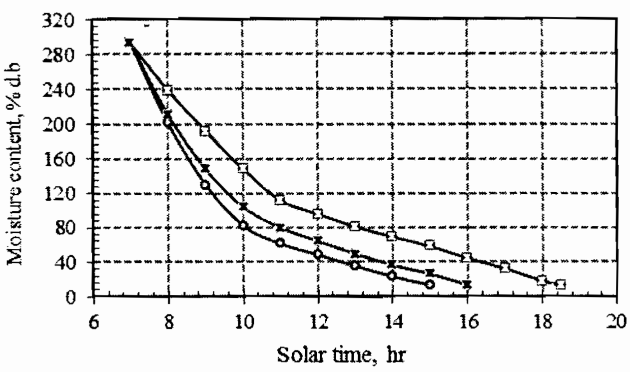

Fig. 8: Moisture content of lemon grass during solar time of different systems of air solar collector.

Drying rate:

Figure 9 shows the average value of drying rate (g_{water} per min) of lemon grass at different systems of air solar collector. It shows that, the highest moisture content (1.58 g_{water}/min) was obtained with air solar collector system III, followed by system II (1.4 g_{water}/min) and system I (1.1 g_{water}/min). The previous results are due to the improvement of energy gained, which was added to the air flow rates of systems III and II by the addition of an absorbed plate to the solar collector of system I.

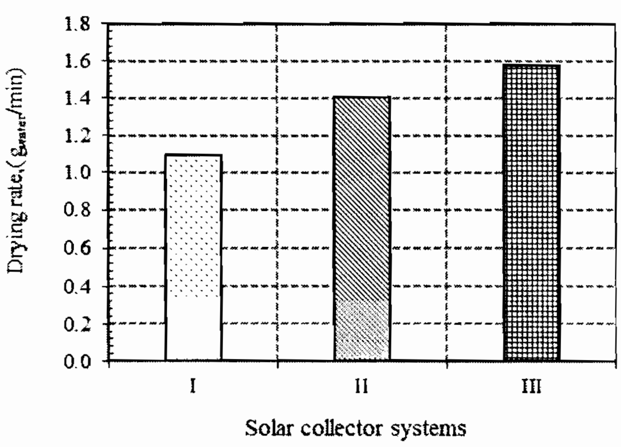

Fig. 9: Lemon grass drying rate by using different air solar collector systems.

CONCLUSION

Additional absorber plate to the normal air solar collector and the additional air flow passing upper and lower the absorbed plate, increased (as average values) outlet air temperature from 42.33 to 50.14 (with 18.5% increasing ratio), followed in increasing in energy gained from 51.82 to 73.09 W/m^2 (with increase of 41%), lemon grass drying rate from 1.1 to 1.6% d.b. (with increase of 37.5%), and finally, increasing the thermal efficiency of the air solar collector from 16.01 to 27.09% (with increase of 69.02%).

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استخدام أنظمة مختلفة للمجمعات الشمسية الهوائية لتجفيف حشيشة الليمون

رجب إسماعيل مراد

قسم الهندسة الزراعية-كلية الزراعة – جامعة الفيوم

أجريت هذه الدراسة بغرض دراسة كفاءة الأداء الحراري لثلاث أنظمة لمجمع شمسي يقوم بتسخين الهواء بغرض استخدامه في عملية التجفيف. ثم استخدام نبات حشيشة الليمون في اظهار تأثير تلك الأنظمة علي عملية التجفيف. اعتمد النظام الأول علي وجود لوح امتصاص من الصاج أسود اللون يعمل كمادة ماصة للطاقة الشمسية داخل صندوق خشبي ذو سطح شفاف (زجاج)، بحيث يسحب الهواء بمروحة مثبتة فى نهاية المجمع وفى بداية مدخل غرفة التجفيف. تضمن النظام الثاني تزويد النظام الأول بلوح امتصاص اضافي من الصاج أسود اللون مثبت في منتصف المسافة الرأسية للصندوق الخشبي بحيث يكون هناك ممر علوي للهواء ومواجه للغطاء الزجاجى، والممر الأخر بين لوحي الامتصاص، وفي هذا النظام يمرر هواء التجفيف من خلال الممر السفلي فقط مع غلق مخرج الممر العلوي. أما في النظام الثالث فتم استخدام الممر العلوي والسفلي معا لعبور هواء التجفيف.

أوضحت النتائج تفوق النظام الثالث علي النظام الثاني بنسبة بسيطة بينما حدث تفوق كبير للنظامين الثالث والثاني علي النظام الأول في كل من درجة حرارة الخروج، حيث تبع ذلك تفوق في الطاقة الممتصة والمكتسبة، كما حدث نجاح كبير في الكفاءة الحرارية للنظام الثالث على النظام الأول، بينما كان هناك تفوق نسبي للكفاءة الحرارية للنظام الثالث علي النظام الثاني.

وعلى صعيد عملية تجفيف حشيشة الليمون Lemon grass (*Cymbopogon citratus*)، تم التوصل إلى المحتوى الرطوبي المتوازن (١٣,٢٪ علي أساس جاف) لأنظمة التجفيف الثلاثة المستخدمة خلال ١١,٥، ٩ و ٨ ساعة تجفيف علي الترتيب، مما جعل تفوق النظام الثالث علي كل من النظامين الثانى والأول فى معدل التجفيف والذى بلغ ١,٦، ١,٤ و ١,١ جمماء/دقيقة مع النظام الثالث، الثاني والأول علي التوالي.