THERMAL AND ENVIRONMENTAL ANALYSIS OF DEVELOPED SOLAR DRYER ENHANCED BY PV MODULE AND HEAT STORAGE UNIT FOR DRYING CANTALOUPE

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ABSTRACT

A developed design of solar dryer with water storage heat unit was conducted to can operate the drying process continually at day and night using the stored heat. It is used to avoid the problems of sun drying as dust, pests, poor quality for dried products and long time for process. This design could provide also further improvement for the performance of the pervious same type of solar dryers. It has the following advantages such as: movable to can be directed according to sun's angle, besides it could connect to photovoltaic modules and batteries to can store energy and operate dc fan and dc water pump in the drying system. It is found suitable for drying agricultural products as Cantaloupe.

The average of daily PV efficiency during daytime was 9.1%, collector efficiency 54.38% and dryer efficiency was 23.32%. The energy payback time was 1.21 years and CO_2 mitigation over the lifetime was 36.48 tons. The time of the dried cantaloupe from this solar dryer is shorter than the dried products in the open sun. This system is useful for farmers in arid areas, and non-electrical zones.

Keywords: *Environmental, Solar drying, storage, PV, Cantaloupe.*

INTRODUCTION

Cantaloupe is a sweet fruit which used as a fresh in the Arab countries and in Saudi Arabia, however it could use as a dried products to use in/as sweets during all over the year. Drying of agricultural products in Saudi Arabia is normally carried out by artificial methods with high costs or by traditional sun drying method with not high quality for products and long time for the drying process.

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Sun drying method is a very slow and it often results in inferior quality of materials due to dependence on weather conditions and vulnerability to contaminate with insects, pests, dust and dirt. Sometimes, continuous rain occurs for a few days or even for a week, spoils the whole amount of seeds restricting traditional sun drying.

On the other hand, industrial drying requires high cost involvement. Solar energy is one of obtainable renewable energy in Kingdom of Saudi Arabia (KSA). Hence, it is the high time for the researchers to develop suitable drying technology for production of high quality of agricultural products coping with the socioeconomic condition of Saudi Arabia.

Using indirect dryers enable better and faster drying as the damage of products is reduced during the drying process. In order to improve the quality of food products in terms of color, texture and taste many types of indirect solar dryers were developed. Some types of indirect solar dryers were built to decrease the drying time and achieve better efficiency for short period, **Hussain et al., (2008), Zomorodian and Dadashzadeh, (2009) and Gatea (2011)**.

The air pollution and CO_2 emissions comes from the enlarge of using fossil fuel. So, it is necessary to find other renewable energy sources. Photovoltaic (PV) as environment friendly renewable source of energy can contribute significantly to a sustainable development because it has gained worldwide recognition as a reliable. In Middle Eastern countries, the abundant solar radiation made most appropriate for development of solar PV system. Solar energy can reduce up to 27%-80% of fossil fuel cost by using drying food, according to **Prakash and Kumar (2013).** The use of solar dryers could avoid of the direct contact between product and the ground during drying, besides prevents the penetration of insects in the dried products, **(Labed et al. 2016).**

Fatouh et al., (2006) reported that the specific energy consumption of dryers could define as the amount of the energy required to remove 1 kg of water from wet substance. It is directly affected by the methods of drying represented by heat transfer, dryer throughput, and mixing of the bed material. It could also affect by different factors as physical and chemical properties of wet materials, climatic conditions, and operating options **(Tarhan et al., 2011).**

According to **Bal et al. (2010) and (2011)** there are two ways for thermal energy storage: chemical or thermal method. It is preferable to apply thermal way approach in solar drying. In this way, using sensible heat storage can be used by increasing the temperature of a liquid or a solid. That means, increasing their internal energy during high radiation period for discharged during the low radiation period. There are factors affecting the quantity of stored energy which are the characteristics of the stored materials and the diversity of the radiation. The best liquid storage material is water because of its cost, its specific heat properties, and the temperature range of its use **(Sharma et al., 2009 and Bennamoun, 2013)**.

Some investigations of latent heat storage for a water solar heating system and electricity as auxiliary source were conducted (**Amer et al., 2010 and Reyes et al., 2013)** for drying mushroom. Otherwise, few researches of latent heat storage for a water solar heating system was conducted to be as the only supplementary source for the solar system by **Luna et al. (2010)** for pine wood solar drying **and Nabnean et al. (2016)** for drying osmotically cherry tomatoes.

However, a movable solar dryer has been developed to be suitable for drying of fruits and vegetables and to avoid usage of electricity supply and saving its cost, a photovoltaic module, storage heat unit and storage batteries will be incorporated to operate electric dc blower and electric dc water pump. It may be operated during sunny days independent of supply and in adverse weather (rainy, cloudy and foggy) using the storage energy. This dryer will be tested in the small-scale as well as in the small farmers field and a large-scale dryer for vegetables and fruits drying will be upscaled. The local manufacturers, mechanics and farmers will be trained so that they can fabricate and operate the dryers themselves and they can produce quality dried vegetables and fruits using appropriate production technology.

Objectives of the research:

(1) To evaluate the thermal performance of the solar drying system.

(2) To study the environmental impact of developed design for solar dryer supported by sensible heat storage and photovoltaic module, suitable for drying cantaloupe as an example for drying fruits.

MATERIALS AND METHOD

1. The developed solar drying system:

All the solar drying setup and the experiments will be done at College of Agricultural & Food Sciences, King Faisal University (KFU), Al Hufuf, Al-Hasa, Saudi Arabia (25° 18′ N Latitude, 49° 29′ E Longitude), in March 2018. The drying experiments were driven at day-time from 8 a.m to 6 p.m (10 h), and continues at night time till the sun-shine at next day. The solar drying system consists of the following items as in Fig. 1:

1.1. The solar collector connected with a heat storage unit:

The solar collector with dimensions 180x120x20cm height is cover by glass (4mm) to cover the absorber which is fixed under the glass. The collector was oriented to the south and with angle 30°C slope. The horizontal angle of the collector could change according to the direction of the sun by movable wheels. The collector was insulated using wood 5mm thickness. In the solar collector, the drying air could be heated and pass to the drying room over a black painted curved metal. Part of the collected heat is given to the water during sun-shine hours by the hose type (1.25cm diameter) as a heat exchanger. In addition, a water reservoir with 120cm height and 90cm diameter insulated by fiber-glass was connected to the heat exchanger and collector to use as a unit for storing heat in water. At night the stored heat in the water reservoir is used to raise the air temperature inside the dryer by the water-to-air through the heat exchanger (hose type). There is a DC water pump operated also by photovoltaic module to help the water moving from the tank to the heat exchanger inside the solar collector. The tank is located over a table with 80cm height.

1.2. The drying chamber:

The surface of the drying section is located after the solar collector. Its dimensions 150 x 100 x 180cm height. It has movable wheels with 50cm height. An insulated flexible tube will be as a connection for air passing from the collector to the drying chamber. The fresh products could be placed over the three trays of wooden frame and plastic net. The distance between every two trays is 40cm. The heated air passes across the fresh products inside the chamber. A chimney was connected to upper part over 60cm from the chamber. There is a DC fan (20cm diameter) operated by photovoltaic module will put in the chimney to help the air removed from the drying chamber to get outside. The drying chamber and chimney are insulated by fiberglass 5mm.

1.3. PV module

A photovoltaic module (150watts) with dimensions 150x70x35cm thickness was connected to the solar system to operate the DC fan (80W) and DC water pump (45W). It connected to battery to store the rest of energy during the sun hours to use this energy to operate the DC fan and pump at night.

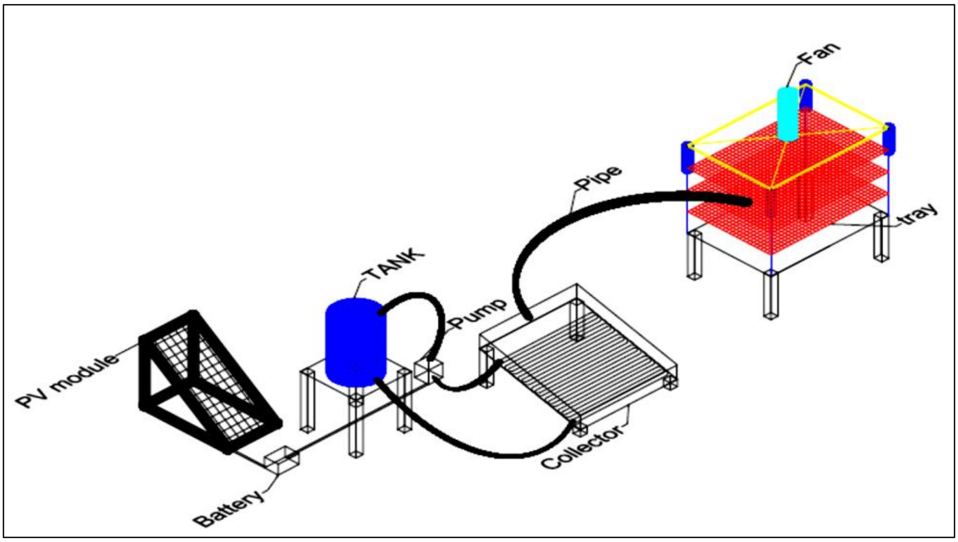

Fig. 1. Schematic diagram of developed solar drying system.

2. Characteristics of the Cantaloupe:

Local type of cantaloupe which cultivated in AL-Hasa was using as an example of fruits to evaluate the thermal and environmental performance of the solar drying system. The fresh cantaloupe (10kg) was divided into cubes in 5mm to be dried to evaluate and test the dryer.

2.1. Determination of the moisture content for fresh product:

The initial moisture content of fresh and dried material was determined by atmospheric air oven method at 105 ± 2 °C for 24 hours, **(AOAC, 2003)**. Moisture content (wet basis) could be calculated from the mass difference between the original and dried sample and expressed as percentage of the original sample.

2.2. Determination of the moisture content during drying process:

For the determination of the moisture content, wet basis, of the material at any time "t_i" during drying process, the following equation could be used:

$$Mw_i = \frac{W_i - W_d}{W_w} \times 100 \qquad (\%) \tag{1}$$

Where:

Mw_w moisture content at time t_i,, wet basis of the material.

W_d mass of the dried sample, (kg)

W_i mass of the material at time t_i,, (kg).

The determination of the material mass was done by weighing the drying tray with its load of material at any time during the drying process.

3. Determination of the air characteristics:

3.1. Air temperature:

Multi-channel Temperature Meter (Data logger + 32 thermocouples) is used for measuring the air temperature at 32 points.

3.2. Air velocity:

Anemometer (accuracy 0. 1 m per second) is used for measuring air velocity.

3.3. Solar Radiation:

Pyranometer with handheld read-out unit / datalogger (USA) is used for measuring hemispherical solar radiation in Wm^2.

4. Thermal Balance analysis

The thermal balance was used for energy analysis of product drying process in hourly basis in order to optimize the drying conditions as the following:

4.1. Thermal balance for the solar collector:

The collector efficiency (η_{coll}) is given as:

$$\eta_{coll} = \frac{Q_{u,coll}}{Q_{in.coll}} \tag{2}$$

The useful energy to the collector could be calculated as:

$$Q_{u,\ coll} = Q_{in,\ coll} - Q_{losses} \tag{3}$$

4.1.1. Heat gain to the solar collector:

The energy input for every hour to the collector, $(Q_{in,\ coll})$ is estimated as **(Tawon et al. 2008):**

$$Q_{in,coll} = Q_{sol.coll} = A_{coll} \int_0^t I_{coll} \quad (4)$$

where: A_{coll} is the collector area (m^2), I_{coll} inclined solar radiation (W/m^2). The hourly useful energy received from the collector to the drying chamber in (Wh), is the heat gain (net) from solar collector to the dryer, $Q_{u,coll}$, (**Duffie and Beckman, 1991):**

$$Q_{u,\,coll} = m_a\, C_{p,a}\, (T_{a,in} - T_{a,\,out}) \quad (5)$$

$$m_a = \rho_a\, V_a = \rho_a\, u_a\, A_{coll} \quad (6)$$

where: u_{air} is the air speed (m/s), and ρ_{air} is the air density (kg/m^3).

4.1.2. Heat loss from the solar collector:

Since, the heat loss of the collector (Q_{loss}) could be calculated from the following equation:

$$Q_{loss} = Q_{\mathbf{air\text{-}wat}} + Q_{\mathbf{c}} + Q_{\mathbf{r}} + Q_{\mathbf{loss,\,tube}} \quad (7)$$

For the collector of 1.8 m^2 area, the absorptivity of black cover of the corrugated galvanize plate is 0.9, emissivity is 0.1 while transparency of the top glass cover is about 92%.

1. Heat losses from air to the water "$Q_{air\text{-}wat}$":

The heat losses from air passes inside the solar collector to the water passes inside hose could be determined using the following equation **(Incropera and DeWitt, 1996):**

$$Q_{air\text{-}wat} = m_{air}\, c_{p,air}\, \Delta T_{air} = m_{wat}\, c_{p,wat}\, \Delta T_{wat} = U_{coll}\, A_{coll}\, dT \quad (8)$$

Where U_{coll} is the overall heat transfer coefficient for the surfaces of solar collector (W/m^2K), and dT is the temperature difference (K).

2. Heat losses by convection from the collector "$Q_{c,\,coll}$":

Convective heat transfer coefficient ($h_{gl\text{-}amb}$) from the glass cover of collector to ambient due to wind (W_S) is computed as (**Duffie and Beckman, 1991):**

$$h_{gl\text{-}amb} = \mathbf{2.8 + 3.0}\, W_S \quad (9)$$

A DC fan for axial flow was fixed in chimney on the upper part of the drying chamber over the drying trays was used to remove the moisture-laden air from the dryer, however it forced the air from the collector to the drying chamber. The conditions of air flow over the absorber of the collector were determined by calculating the Reynolds Number *(Re)* and Nusselt number *(Nu),* then the convective heat transfer coefficient "$h_{ab\text{-}air}$"

for air over absorber surface (between the absorber and air inside the solar collector) can be calculated as follow **(Incropera and DeWitt, 1996)**:

$$Re = \frac{u_{air,coll} * \rho_{air} * D_h}{\nu_{air}} \quad (10)$$

$$Nu = \frac{h_{ab-air} * D_h}{k_a} = 0.0158\ Re^{0.8} \quad (11)$$

$$h_{ab-air} = \frac{k_{air} * Nu}{D_h} \quad \left(\frac{W}{m^2.{}^\circ C}\right) \quad (12)$$

Where "D_h" is the hydraulic width of air passes (m); and it could be calculated from the following equation according to **Cengel (2003):**

$$D_h = \frac{4\ D * H}{2\ (D+H)} \quad (13)$$

Where:

D_{coll} = 1.2 m (actual width of air passes inside collector), H_{coll} = 1 m (actual height of air passes),

Where D_h is characteristic width of air passes (m), ν_{air} is kinematic viscosity of air (m^2/s), T_{ab} is mean temperature of absorber (62°C = 335 K), and T_{amb} is the surrounding air temperature (29°C = 301K). Therefore, $h_{c,\ ab-air}$ = 1.7 W/m^2.K; and the heat loss below the absorber was obtained from:

$$Q_{c,(ab-air)} = A_{ab} * h_{ab-air} * (T_{ab} - T_{amb}) \quad (14)$$

Where: A_{ab} contact area between absorber and air inside collector (m^2)

T_{ab} surface temperature for absorber, (K).

3. Heat losses by radiation from the collector ($Q_{r,coll}$):

Radiative heat coefficient from the collector glass cover to sky ($h_{r,gl-sky}$) as well as radiation heat transfer coefficient between collector glass cover and absorber ($h_{r,ab-gl}$) could estimate as (**Duffie and Beckman, 1991**):

$$h_{r,gl-sky} = \varepsilon_g\ \sigma\ \left(T_g^2 + T_s^2\right)\left(T_g + T_s\right) \quad (15)$$

$$h_{r,ab-gl} = \frac{\sigma\left(T_{ab}^2 + T_{gl}^2\right)\left(T_{ab} + T_{gl}\right)}{\frac{1}{\varepsilon_{ab}} + \frac{1}{\varepsilon_{gl}} - 1} \quad (16)$$

Where: ε_{ab} is the absorber surface emissivity (taken as 0.98), ε_{gl} is the glass surface emissivity (taken as 0.92) and σ is Stefan-Boltzmann which equal to (5.67 x 10^{-8} W/m^2.K^4)**.**

The sky temperature (T_{sky}) is computed as (**Duffie and Beckman, 1991**):

$$T_{sky} = 0.0552\ (T_{amb})^{1.5} \quad (17)$$

where T_{sky} and T_{amb} are both in Kelvin.

4. Heat losses from the connection tube between collector and dryer:

The insulated connection tube between the collector and drying chamber is cylindrical in shape, insulated by fiber glass and made from tin, The heat losses from the connection tube ($Q_{loss,tube}$) can be expressed as:

$$Q_{loss,tube} = 2\pi LU\Delta T = 2\pi L \frac{(T_i - T_\circ)}{\left(\frac{1}{r_i h_i} + \frac{ln\left(\frac{r_2}{r_1}\right)}{k} + + \frac{1}{r_\circ h_\circ}\right)} \qquad (18)$$

Where: r_i and r_o are the inner outer radius of layer (m), respectively.

$h_o = h_d$: is the conductive heat-transfer coefficient across the insulation (W/m^2.°C) and estimated by:

$$h_d = \frac{K_{fg}}{d_i} \qquad (19)$$

k_{fg} equal to 0.043 W/m.°C for fiber-glass and d_i is the average mean of insulation thickness (0.05 m).

4.2. Thermal balance for drying chamber:

The dryer efficiency (η_{dryer}) is given as:

$$\eta_{dryer} = \frac{Q_{evap}}{Q_{in}} \qquad (20)$$

However, the thermal balance for drying chamber could be summarized as:

$$Q_{net,\,dryer} = Q_{net,\,coll} - (Q_{evap} + Q_{loss}) \qquad (21)$$

4.2.1. Heat gain to the drying chamber:

The useful heat gain from the collector to the drying chamber during the drying process can be expressed as:

$$Q_{net,\,coll} = Q_{u,coll} - Q_{loss,tube} \qquad (22)$$

4.2.2. Heat output from products inside drying chamber:

It is the thermal heat output which divided into evaporation heat and sensible heat and could determine as the following:

The total thermal energy by evaporation (Q_{evap}) could be calculated by:

$$Q_{evap} = Q_{sen} + Q_{latent} \qquad (23)$$

1. Sensible heat to raise products temperature (Q_{sen}) can be estimated by:

$$Q_{sen} = m_p\, c_{p,p}\, \Delta T_t = \rho_p\, V_p\, c_{p,p}\, \Delta T_p \qquad (24)$$

Where:

m_p rate of fresh product, (kg/s).

$c_{p,p}$ specific heat of product, taken as 4 kJ/kg.°C **(**ASHRAE**, 2006)**

ρ_p density of product, taken as 670 kg/m^3 **(Mohsenin, 1986)**

$T_{p,in}$ product inlet temperature to dryer, (°C)
$T_{p,out}$ product outlet temperature from dryer, (°C)

2. Latent heat to vaporize water from product (Q_{Latent}) estimated by:

$$Q_{Latent} = m_{wat}\, \lambda_{wat} \qquad (25)$$

Where:

m_{wat} rate of water removed from product, (kg/s)
λ_{wat} Latent heat of water vaporization taken as 2300 kJ/kg **(Cengel, 2003).**

3. Heat Losses from sides of drying chamber:

Due to the insulation for the sides of drying chamber, the losses by convection and radiation heat losses from the drying chamber is very few and could be neglected.

4.3. Thermal balance for PV panel:

$$Q_{net,\ pv} = Q_{gain} - Q_{oper\ loss} \qquad (26)$$

The PV efficiency (η_{PV}) is expressed as the following equation:

$$\eta_{PV} = \frac{Q_{\ out,PV}}{Q_{in.PV}}\ x\ 100 \qquad (27)$$

The energy output and energy input to the PV could be calculated as:

$$Q_{\ out,PV} = V_{\ max,PV}\ X\ I_{\ max,PV} \qquad (28)$$

$$Q_{in.PV} = I_{PV}\ x\ A_{PV} \qquad (29)$$

Where:

V_{max} max. PV power voltage (17.8V), I_{max} max. PV power current (8.5A)
A_{PV} area of PV (m^2), I_{PV} inclined solar radiation (W/m^2).

The overall thermal efficiency ($\eta_{overall}$) of the solar drying system:
It could be expressed as follows:

$$\eta_{overall} = \frac{\sum Q_{\ out}}{\sum Q_{\ in}}\ x\ 100 \qquad (30)$$

5. Environmental analysis:

5.1. Energy payback time:

It is the time required to payback the embodied energy of the developed solar drying system and estimated as **(Prakash and Kumar, 2014):**

$$Time\ of\ energy\ payback = \frac{Embodied\ energy}{Annual\ energy\ output} \qquad (31)$$

Where: the embodied energy is the total energy required to produce any items or services, as show in Table 2.

5.2. Net mitigation in CO_2 emissions over the lifetime:

In the solar drying system, a PV operated to remove air from the dryer which does not need any other energy during operation, therefore, it is non-polluting and environment friendly.

The net mitigation in CO_2 emissions over the lifetime (kg) could be calculation from the equation:

$$\text{Net mitigation over the lifetime} = \text{Total } CO_2 \text{ mitigation} - \text{Total } CO_2 \text{ emission} \quad (32)$$

The lifetime of the system (taken 30 years) as found by **Nayak et al. (2011).** The emission of CO_2 per year could estimate as (Prakash and Kumar, 2014):

$$Co_2\ emission/year = \frac{Embodied\ energy \times 0.98}{Lifetime} \quad (33)$$

Since, Coal is generated electricity as average of 0.98 kg of CO_2/kWh. However, the CO_2 mitigation over the system lifetime could by calculated by **Nayak et al. (2011)** as the following:

$$Co_2\ mitigation\ over\ the\ system\ lifetime = Q_{em} \times \frac{1}{1-L_a} \times \frac{1}{1-L_{td}} \times 0.98 \quad (34)$$

where: Q_{em} is the embodied energy (kWh) for the PV solar dryer which show in Table 2, the losses due to poor domestic appliances is L_a (taken as 10%). The losses of transmission and distribution are L_{td} (assume 45%), as reported by **Nayak et al. (2011).**

The mitigation for CO_2 can be used as a measure for climate change potential. The solar thermal energy and PV system could use to operate the developed dryer. This process could reduce the CO_2 emission comparing with other traditional fuel systems, that can use to raise the temperature of air and generate of electricity. However, CO_2 emissions from alternative power production technologies could compare with cumulative CO_2 mitigations which record per kilowatt hour.

6. Annual Energy outputs

The total Energy output per year from PV solar drying system equals the sum of net output of electricity from PV and output of thermal energy for evaporation from the dryer **(Nayak et al., 2012).**

The total thermal energy for evaporation per hour could determine as the following:

$$\text{Average of Net annual thermal output} = Q_{evap}\ X\ N_{dh}\ X\ N_{ddy} \quad (35)$$

The average of Net annual electrical output from a PV panel could determine as the following:

$$\textit{Average of Net annual electrical output} = Q_{out,\,PV}\ X\ N_{sh}\ X\ N_{sdy} \quad (36)$$

where: N_{dh} daily drying hours, N_{sh} daily sunshine hours, N_{ddy} No. of drying days per year (300 days), N_{sdy} No. of clear yearly sunny days (300 days). However, the total thermal energy for evaporation per hour Q_{evap} was calculated by equation 23, and the average of Net electrical output per hour $Q_{out,\,PV}$ was calculated by equation 28.

RESULTS AND DISCUSSION

3.1. the fresh and dried product characteristics:

Fig. 2 showed the Changing in the moisture content of cantaloupe cubes 5mm for solar and sun during drying time (day and night).

The moisture content of fresh cantaloupe ranged from 90 to 91% wet basis and the final cantaloupe was between 8-9%. The time of the solar drying process for cantaloupe cubes was around 26 h, however it needed to 34 h by sun drying to reach to the final moisture content.

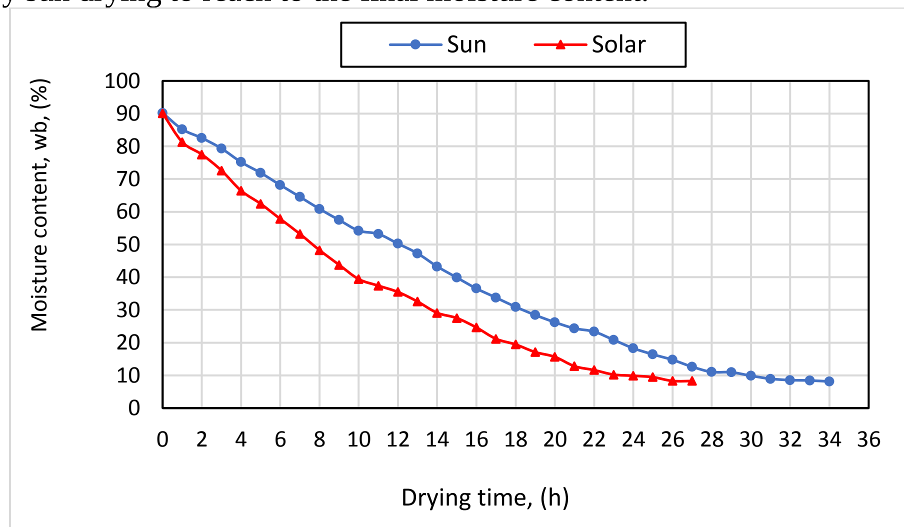

Fig. 2. Changes in the moisture content of cantaloupe cubes 5mm for solar and sun during drying time (day and night)

3.2. Drying air characteristics:

There were a continuously variation in the drying air characteristics through the solar drying experiments due to the continuously changing in the ambient air characteristics.

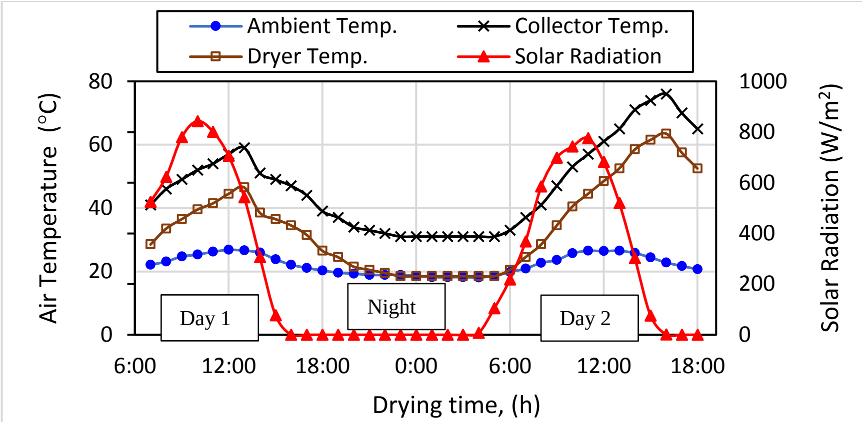

Fig. 3. Changes in the ambient, collector and dryer air temperature with solar radiation during drying time

Since the ambient air temperature ranged from 20.1 to 28.9°C, ambient air relative humidity from 8.5 to 49.8 %, while, the drying air from 19.8 to 62°C, drying air relative humidity from 5.5 to 36.9 %. The average solar radiation was ranged zero at night to maximum 870 W/m^2 at the day-time and the average speed of ambient air was about 1.5 m/s. The maximum difference between the ambient air temperature and the drying air temperature was around 40°C.

However, the difference between the air temperature inside the solar collector and the drying air temperature was around 12-13°C. The average air flow rate through the drying chamber was 2 m^3/min. Fig. 3. Shows the changes in the ambient, collector and dryer air temperature with solar radiation during drying time.

3.3. Thermal Balance on the Solar drying system:

The daily average useful heat gain by the Solar drying system during the experimental period was 1260 - 1730 Wh. The amount of useful heat obtained varied from time to time during the experimental period due to the variations in weather conditions (**Amer et al., 2010**). By increasing the ambient air temperature, the useful heat gain was reduced due to decrease the difference in temperature between the hot air inside the solar drying system and the air passing through the solar collector to the solar drying system. It should be noted that, increasing the difference in temperature between inside the Solar drying system and surrounding air let to increase the heat losses and vice versa.

From the mathematical equations (2) to (30), for the solar drying system, the values of calculated energy (Wh) for parts of collector, solar dryer and PV module were showed in Figs. (4 and 5). The infiltration heat from solar dryer through doors, handle, hinges and hooks was very small amount and was neglected. The rest between the useful heat output from PV module and the required heat to operate DC fan (80 W) and DC water pump (45 W) could be stored in battery to be used at the cloudy hours through the drying experiments.

From Figs. 4 and 5, the experiment was taken two days only, at the first the drying process spent time around 10 hours, the process continuously during sunset and at night by using the stored energy in the water and exchanged to air inside the collector, and the process was taken at the second day around 10 hours also.

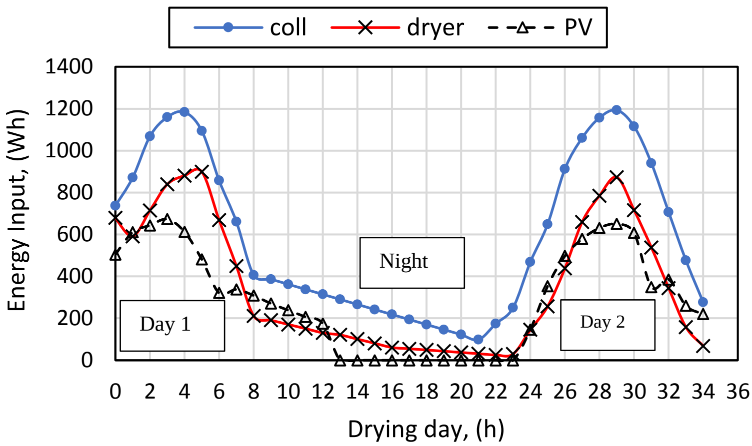

Fig. 4. the calculated energy input for collector, drying chamber and PV

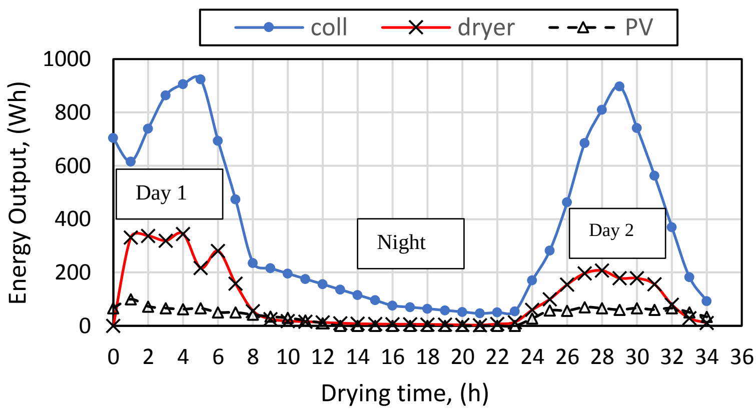

Fig. 5. the calculated energy output for collector, drying chamber and PV

Fig. 6 was showed that the efficiency for the collector in the first day was higher than in the second day, but the energy losses was lower in the first day than the second day. The same sequence was for the dryer and the value of output energy from the dryer was higher in the first day than the second day. For the PV, the output energy was low in both days.

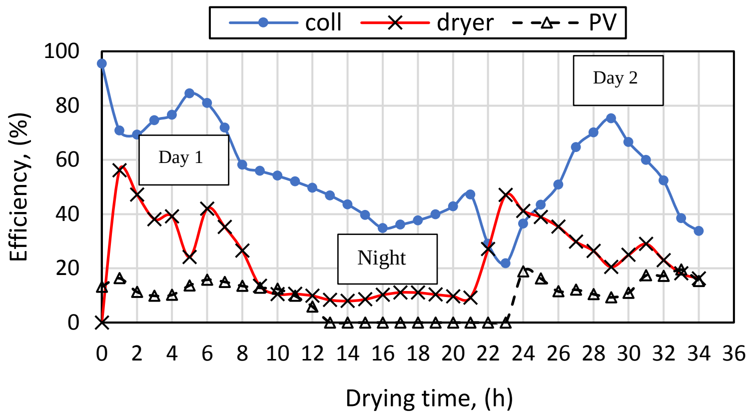

Fig. 6. the efficiency for collector, drying chamber and PV

It refers to the best mean efficiency for collector was found at the the mid-day between 12:00 to 2:00 p.m graduated till the sun set. However, it still over zero after sun set and during the night because the energy transfer from water to air till the sun raise at the next day.

Table 1 showed the average of daily PV efficiency, collector efficiency and dryer efficiency. Whereas, the average overall efficiency for cantaloupe cubes 5mm experiments are found to be 21.96%.

Table 1. The calculation efficiency (%) for the items of solar drying system.

No	Item	Efficiency (%0
1	Solar Collector	54.38
2	Drying chamber	23.32
3	PV module.	9.1

The dryer efficiency was high in the first period of drying process to remove a large amount of water from fresh material and then decreased till the sun set and be low at the night time and after sun set at the second day increased again then decreased slightly till the end of the drying process.

The PV efficiency was related in the opposite direction with the collector efficiency because its efficiency was decreased with the high temperature at the mid day.

3.4. The Environmental analysis and the performance of PV

The embodied energy of different materials that is used in the solar drying system was presented in Table 2.

Table 2. Embodied energy of calculation data for developed solar dryer.

No	Materials	Embodied energy (kWh/kg)	Embodied energy (kWh)
Collector			
1	Plywood	2.88	18.32
2	Absorber	9.636	19.53
3	PVC pipe	19.39	42.23
4	Glass cover	7.28	49.76
5	Black paint	25.11	11.17
Dryer			
1	Galvanize Aluminum sheet	10.197	289.11
2	Glass wool	4.044	18.19
3	Hinges	55.28	10.99
4	Handle	55.28	5.340
5	Steel screw	9.67	1.560
6	Hookes	55.28	5.280
7	DC fan	39.05	4.930
Heat Storage unit			
1	Water tank	5.83	15.830
2	DC water pump	28.98	3.980
Solar cell system			
1	Polycrystalline solar cell	1130.6(kWh/m^2)	1137.83
2	Battery	148.45	450.05
Total embodied energy (kWh)			1934.02

From **Table 2,** the embodied energy of different materials at collector, dryer and PV in (kWh/kg) was reported by **Eltawil, et al. (2018).** However, the overall embodied energy for these materials (kWh) was calculated using the weight in kg of each one.

Energy payback time was found to be 1.21. Whereas, the net CO_2 mitigation over the lifetime found to be 36.48 tones.

Since the performance of PV system in outdoor is quite different from the standard conditions, the performance is evaluated under ambient conditions. Results showed that the PV power output and module temperature were directly proportional to insolation and ambient temperature.

The average of daily T_{PV} was 52 C while, T_{amb} was 29 C. The maximum power generated by PV module was recorded at noon time. The PV module temperature was increased at noon, and this causes an increase in the short circuit current (I_{sc}) and a decrease in the open circuit voltage (V_{oc}). The T_{PV} was increased due to high insolation heating, high T_{amb} and low wind speed; and consequently, low heat transfer from the PV module to the ambient. These results were agreed with **(Prakash et al., 2016).**

CONCLUSION

This developed design for solar drying system will help reducing post-harvest losses of vegetables and fruits to a considerable extent. It will save the vegetables and fruits from spoilage during bad weather and will improve the quality. Quality fruits will produce good products enhancing food security of the country. If the results of this research are disseminated properly, growers and traders can produce their dried vegetables and fruits themselves reducing dependability on imported dried products.

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الملخص العربي

التحليل الحراري والبيئي لمجفف شمسي مطوّر ومدعم بواسطة وحدة تخزين للطاقة وخلية شمسية لتجفيف الكنتالوب

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تم إجراء تصــميم متطور لمجفف شــمســي مزود بوحدة تســخين المياه لتتمكن من تشــغيل عملية التجفيف باسـتمرار ليلًا ونهارًا باسـتخدام الحرارة المخزنة. هذا النظام الشـمسـي المطور صـمم ليستخدم في التغلب علي مشاكل التجفيف الشمسي الطبيعي مثل الأتربة والحشرات وجودة الغير العالية للمنتجات المجففة وأيضــا زمن التجفيف الطويل. هذا التصــميم يمكن أن يوفر المزيد من التحســين لأداء نفس النوع الســابق من مجففات الطاقة الشــمســية. له المزايا التالية مثل: يمكن تحريك زاوية المجمع الشمسي وفقًا لزاوية الشمس ، إلى جانب أنه يمكن توصيله بخلية الشمسية (الكهروضــوئية) وأيضــا بطارية لتخزين الطاقة وتشــغيل مروحة ومضــخة مياه يعملان بالتيار المستمر في نظام التجفيف. وقد وجد أن هذا المجفف الشمسي المطور مناسب لتجفيف المنتجات الزراعية مثل الشمام.

وكان متوسط الكفاءة الخلايا الكهروضوئية اليومية ٩,١ ٪ ، وكفاءة المجمع الشمسي ٥٤,٣٨ ٪ وكفاءة المجفف ٢٣,٣٢ ٪ ، ووقت اســترجاع الطاقة كان ١,٢١ ســنة وتخفيف ثاني أكســيد الكربون على مدى الحياة كان ٣٦,٤٨ طن. وجد أن جودة شرائح الشمام المجففة من هذا مجفف الطاقة الشمسية أعلى من المنتجات المجففة في الشمس المفتوحة. هذا النظام مفيد للمزارعين في المناطق الجافة والمناطق غير الكهربائية.

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