FORAGE PRODUCTION ENGINEERING BY SOLAR DRYING OF VEGETABLE CROP RESIDUES

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ABSTRACT

Due to animal feed shortage in Egypt, scientists are searching for an alternative feed to meet with this nutritional gap. Agricultural lands are not sufficient for human and animal needs both even in summer or winter seasons. Maximizing the utilization from agricultural by-products is the trend towards problem solving for searching an agricultural residue available in winter season besides Alfalfa to decrease the cultivated area for animal feeding purposes. Peas was at the top crops available in winter season and cultivated much in most places in Delta and besides zones and Peas residues have high content of protein. Peas residues (vine) used for animal feed and cause usually some digestion problems for animal stomach. Drying process contribution can resolve this digestion problem. A semi-cylindrical greenhouse type was used as a solar drier oriented East-West direction and located at Rice Mechanization Center, Meet Eldeebah Village, Kafr Elsheikh Governorate for drying the vegetable crop residues. A solar collector greenhouse type was utilized to provide heated air to the solar drier to enhance its thermal efficiency. The combination of solar drier and solar collector was installed at the same weather conditions during drying experiment (March 2014). The experiments of solar drying of peas residues were conducted under three different levels of drying air velocities (0.5, 1.0 and 1.5m/s), two chopping lengths of peas residues 3 and 6cm and two drying bed depths of 1 and 5cm. The variation in peas residues moisture content was monitored versus drying time. The initial moisture content was of 72%wb.

KEYWORDS: *Solar drying process evaluation, peas residues, exergy analysis.*

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Drying experiments were conducted during March 2014, with an average ambient air temperature of 26.4±2°C. The ambient air relative humidity did not exceed 62% and solar radiation ranged between 597.8 and 801.2W/m^2 during the experimental period. Solar radiation flux incident, air temperature and relative humidity were measured. The thermal efficiency of the solar collector and overall thermal efficiency of the solar drier were calculated. The energy and exergy analyses for peas residues during drying process via mixed-mode forced convection type solar drier were performed with the data obtained from experiments. The productivity of the solar drier was of 1.186kg dried peas residues/m^2 of drier box per day. The results of the current research concluded that drying air velocity of 1.5m/s achieved the highest values of drying air capacity. Specific enthalpy increases by increasing drying air velocity, flow energy and internal energy. It is noticed that the drying air velocity of 1.5m/s also achieved the highest drying efficiency of 68.28% at (12:00PM, 3 drying hours). Peas residues chopping length of 6cm and drying bed depth of 5cm were the most suitable residues distribution on the drying trays.

NOMENCLATURE

A	surface area, m^2
se	specific enthalpy, kJ/kg
C_{pda}	specific thermal capacity, kJ/kg. K
E	exergy, kJ/kg
M	mass of product to be dried, kg
$\dot{m}_{da}$	mass airflow rate, kg/s
M_o	initial moisture content, %db
M_t	moisture content at time t, %db
W	mass of evaporated water from the product, kg at time t
M_{ds}	mass of dry solids, kg
M_W	mass of evaporated water from the product during drying day, kg
sh	specific humidity, %
W_o	initial mass of the dried product, kg
W_t	mass of product to be dried at any time, kg
t	drying time, s

T	temperature, °C
T_{ref}	ambient air temperature, °C
Q_{uda}	useful energy gain rate, W
I	solar radiation incident on the aperture surface, W/ m^2
DR	drying rate, kg water / (kg dry matter. min)
h_o	absolute humidity of air leaving the drying chamber, kg water/kg dry air
h_i	absolute humidity of air entering the drying chamber, kg water/kg dry air
AC_H	drying air capacity based on absolute humidity difference, kg water/ m^3
AC_T	drying air capacity based on air temperature difference, °C
h_{as}	absolute humidity of the air entering the solar drier at the point of adiabatic saturation, kg water/ kg dry air
h_{ref}	absolute air humidity, kg water/ kg dry air
T_{as}	air temperature at adiabatic saturation, °C
T_{ref}	drying air temperature, °C
V	drying air velocity, m/s
G	the solar energy input into the drier, J
ηd	drying efficiency, %
η_c	solar collector efficiency, %
cd1	peas residues chopping length of 3cm and drying bed depth of 1cm
cd5	peas residues chopping length of 3cm and drying bed depth of 5cm
ed1	peas residues chopping length of 6cm and drying bed depth of 1cm
ed5	peas residues chopping length of 6cm and drying bed depth of 5cm
Dep	drying bed depth, cm
Eng	energy gained, W
ΔHl	latent heat of water evaporation, kJ/kg
Cf	crude fiber

Cp	crude protein
NFE	nitrogen free extract
EE	ether extract
DM	dry matter
dh	drying hours
ci	collector inlet
amb	ambient
co	collector outlet
dci	drying chamber inlet
dco	drying chamber outlet
ho	heater outlet

INTRODUCTION

Animal feed sources in Egypt reduce and affect the human consumption. Nowadays problem increases to be worse as a result of the government direction to increase the productivity of major grain crops such as wheat in winter, rice and corn in summer. This cause a competition for the cultivated area .Therefore, this investigation aims to study the possibility .of providing an alternative and non-conventional forage in winter beside summer by solar drying of peas residues. **Abdallah (2010)** stated that there is a gap between the available quantity of green forage and the required amount of animal feed. The gap between the availability and requirement of feed is wide and the estimated shortage is 3.1 million tons of total digestible nutrients per year. The forage gap or the feed shortage has been partially narrowed to become 2.42 million tons because of using new forage resources. He also added that the drying rate which is another important factor in describing the characteristics of the drying process. He concluded that double layer covered plastic greenhouse of 4cm dead air space was the best to be used because of increasing temperature and humidity reduction inside the solar greenhouse drier. **[MOA (2013), in Arabic]** reported that the overall production of peas green in Egypt is 169122 tons for the year 2013; peas contains 5.42g of protein and 5.1g fiber. Green peas contains 14.45g carbohydrates and 5.67g sugars. It also contains 0.4g fats. **Abdallah (1999)** utilized the span form solar greenhouse oriented East-West to serve as a solar collector. Its longitudinal axis is facing to south to capture the possible maximum solar radiation. The plastic cover was of 0.1mm thickness. The outside dimensions of the greenhouse were 4m width and 8m length. The total volumetric capacity was of 82.4m^3 of air. **El-Mashad (2003)** revealed that agricultural wastes represent an important source of bio-energy and valuable products. In Egypt, 18% of the agricultural wastes are used directly as a fertilizer. Another 30% was used as an animal feed. The remainder is burnt directly on the fields or is used for heating in the small villages, using low efficiency burners. These wastes can be used more efficiently as a source of energy and as an organic fertilizer. The anaerobic bioconversion of these materials will result in a net energy production. The utilization of agricultural wastes for the production of energy and compost, combined with using solar energy will save fossil fuel, improve health conditions and the general life quality in the villages. **Ali (1996)** stated that he problem of the shortage of animal feed in Egypt is well recognized. Several efforts had been done to improve the nutritive value of agricultural byproducts. Rice straw, wheat straw, corn stalk, sugarcane, basse vine of broad bean, squash vine and other vegetable wastes were used for increasing the available feed. **Abdelatif (1989)** reported that Egypt is one of the countries, which has solar energy in abundance. It lies within the tropical and sub-tropical regions. It has a value of about 2.2 to 9.4kW of solar energy per square meter per day, and sunshine duration per year extended to about 3000 to 4000 hours. **El-Sebaii *et al.* (2002)** revealed that all drying systems can be classified primarily according to their operating temperature ranges into two main groups of high and low temperature driers. Solar drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilized. Usage of renewable energy technologies has received a considerable attention within the past five years for their potential to help and meet with the basic needs in many countries. Solar energy is used as either the sole source of the required heat or as a supplemental source. **Ekechukwu** and **Norton (1998)** and **Banerjee (2005)** conducted that although, for commercial production of dried agricultural products, forced convection solar drier might provide a better control of drying air; natural convection solar drier does not require any other energy during drying process. Hence, natural convection solar drier is highly preferred for drying food products especially when in thin layers of drying. **El-Sahrigi** *et al.* **(1993)**; **Pangavhane** *et al.* **(2002)** and **El-Kewey (2003)** carried out a study to investigate the utilization of greenhouse for drying grain. They studied the effect of thickness of grain layers, quantity of drying air passing through the grain and agitating operation on the drying process of paddy rice. It was found that the solar drying was more efficient than natural drying in reducing the harvesting initial moisture content of paddy rice. This drying system has the effective characteristics such as simple structure, easy construction and maintenance and low cost compared with conventional driers. The outlet air temperature from the solar heater (greenhouse) was found to be affected by many parameters such as area of solar greenhouse collector, ambient air temperature outside and solar radiation available inside the solar greenhouse. They also found that, the drying air temperature was found to be directly proportional to drier area and solar radiation available inside the solar drier, but it was inversely proportional to ambient air temperature outside the solar drier. **Eldreeny (2015)** exploited the solar energy collected by the plastic greenhouses for drying the agricultural and industrial wastes of banana and showed that the best solar collector is the cylindrical one, based on the thermal collection efficiency. The solar drier in combination with the cylindrical solar collector achieved the highest energy utilization ratio. **Akpinar** *et al.* **(2005)**; **Akpinar** *et al.* **(2006)**; **Celma** and **Cuadros (2009)**; **Akbulut** and **Durmus (2010)**; **Prommas** *et al.* **(2010)** and **Boulemtafes-Boukadoum** and **Benzaoui (2011)** revealed that the air conditioning processes can be modeled as steady-flow processes that are analyzed by employing the steady-flow conservation of mass (for both dry air and moisture) and conservation of energy principles. For the energy and exergy analyses of single layer drying process, empirical equations are generally employed to compute the mass conservation of drying air and moisture, the energy conservation of the process, the relative humidity and enthalpy of drying air. Exergy is defined as the maximum amount of work which can be produced by a stream of matter, heat or work as it comes to equilibrium with a reference environment. In the drying industry, the goal is to use a minimum amount of energy for maximum moisture removal for the desired final conditions of the product. Several studies have been conducted on exergy analysis of food drying. The main objective of the current research is to produce non- conventional forages from vegetable crop residues via solar drying. The specific objectives are to study the effect of chopping lengths and drying bed depths on the drying rate and drying efficiency of peas residues (vine); to investigate the influence of drying air velocities (0.5, 1.0 and 1.5m/s) on the evolution of drying rate; to enhance the efficiency of postharvest processes of agricultural production; to determine the moisture content and drying rate of peas residues and to develop an empirical equation for the drying rate which represents the solar drying process.

MATERIALS AND METHODS

The present research work was carried out at Rice Mechanization Center (RMC) in Meet Eldeebah village, Kafr Elsheikh Governorate located at 31° 07'N Latitude, 30° 57'E Longitude and 20m Altitude (**Abou- Zaher, 1998**), Egypt during March 2014. Drying experiments were conducted with an average ambient air temperature of 26.4±2°C measured by air temperature meter, (Model Chino HNK). Peas residues used in the current investigation were picked up and conveyed to the experimental station of RMC at an initial moisture content of 72%wb. The oven-drying method was used for determining peas residues moisture content at 103°C for 24h (**ASAE, 1996**). Air relative humidity did not exceed 62% measured by relative humidity meter, (Model Chino HNK) and the averaged of solar radiation incident ranged between 597.74 and 801.87W/m^2.

Investigated variables

Peas residues were chopped mechanically with definite lengths of 3 and 6cm. Samples were spread on the drying tray with drying bed depths of 1 and 5cm. Drying experiments were performed with four trays inside greenhouse solar drier. In all experiments, there is an additional thermal energy was supplied to the samples apart from direct solar radiation. A centrifugal suction fan was adjusted to give three levels of drying air velocity of 0.5, 1.0 and 1.5m/s. The effect of these investigated variables on moisture content loss, ambient air temperature, air relative humidity, inlet and outlet temperatures of drying air in the greenhouse solar collector and drying chamber was studied.

Experimental setup

A pictorial view and schematic drawing of the experimental setup, shown in Figures 1 and 2, illustrate the semi-cylindrical solar drier double covered greenhouse in combination with semi-cylindrical greenhouse type as a solar collector. A centrifugal suction fan was mounted on the tray beneath to circulate the drying air inside the drying chamber and force it to penetrate the crop residues. The solar radiation flux was measured and recorded during the drying period started from (10:00AM, 1dh) to (6:00PM, 9dh). The available solar radiation was determined every hour using the equation: Q = R x Ad where Q is the available solar energy, W; R is the solar radiation incident on the greenhouse surface, W/m^2 and Ad is the net surface area of the drier box, m^2. It was measured with a solar radiation sensor (Model H-201). Figure 3 represents the perspective drawing of the semi-cylindrical solar drier double covered greenhouse type. The semi-cylindrical solar drier double covered greenhouse type was manufactured, constructed and installed at the workshop of Rice Mechanization Center, Meet Eldeebah village, Kafr Elsheikh Governorate, Egypt. The dimensions of the greenhouse, which was used as a solar drier, are 100cm width × 200cm length × 80cm height. The dimensions of the drying chamber are 100cm wide × 200cm long and 10cm high.

Drying Kinetics

Drying air capacity

The capacity of drying air for moisture removal depends on its humidity and temperature. Drying air capacity is an important indicator determining the drying air power. Two terms are used to declare the amount of drying force or moisture tension based on absolute humidity difference and on air temperature difference. The drying air capacity based on absolute humidity is defined as the difference between absolute air humidity and the absolute humidity at adiabatic saturation or the difference between drying air temperature and air temperature at adiabatic saturation (thermodynamic wet-bulb temperature). Drying air capacity can be estimated through the following equations (**Doymaz, 2005**):

$$AC_H = h_{ref} - h_{as} \qquad \text{Eqn 1}$$

$$AC_T = T_{as} - T_{ref} \qquad \text{Eqn 2}$$

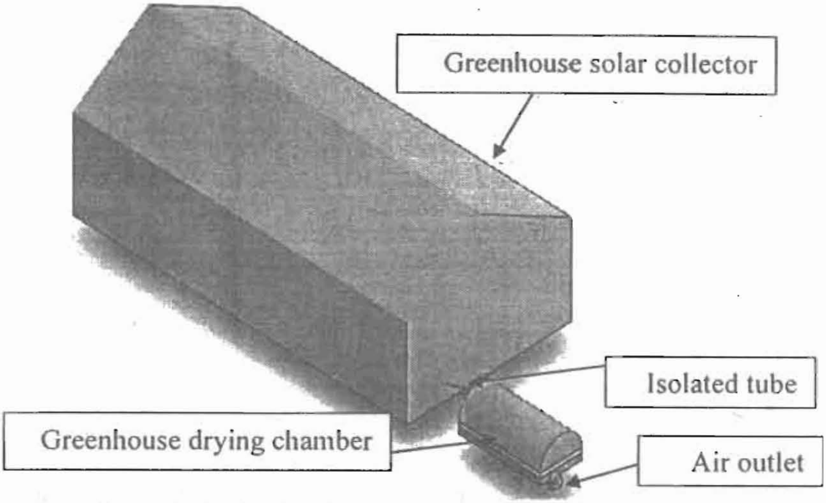
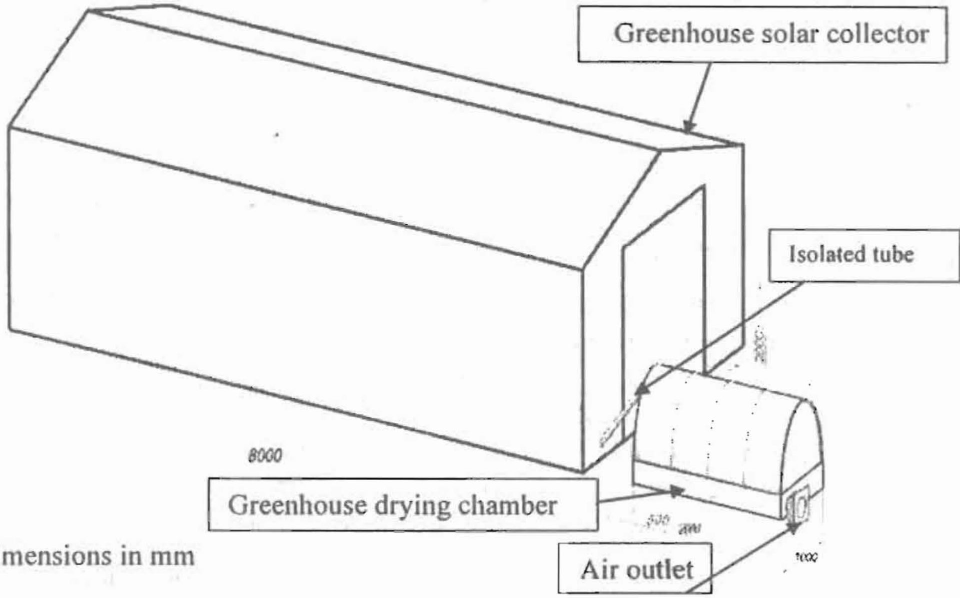
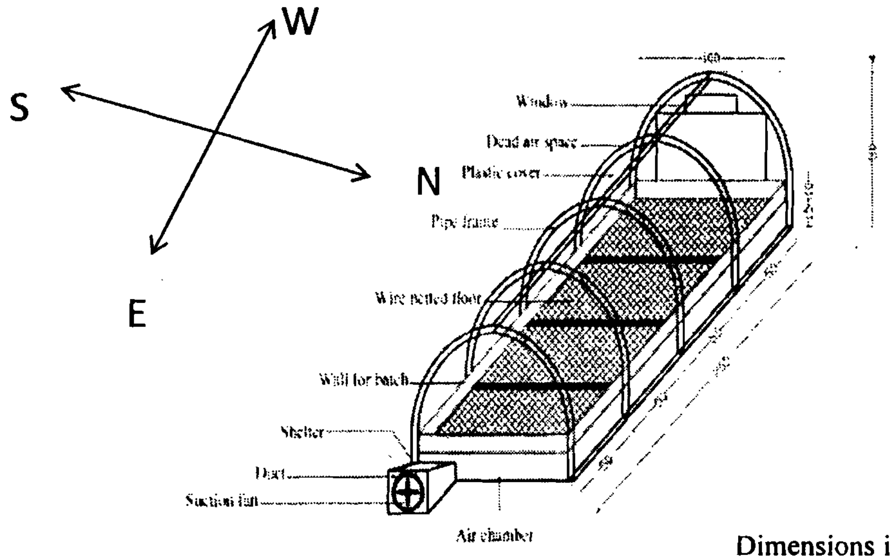


Figure 1. Pictorial view of the experimental setup



Dimensions in mm

Figure 2. Schematic drawing of the semi-cylindrical solar drier double covered greenhouse type in combination with semi-cylindrical greenhouse type as a solar collector



Dimensions in cm

Figure 3. A perspective drawing of the semi-cylindrical solar drier double covered greenhouse type

Determination of the inlet conditions of greenhouse solar collector
The inlet conditions of the solar collector were assumed as being equal to the ambient conditions as:

$$sh_{ci} = sh_{amb};\ T_{ci} = T_{amb};\ rh_{ci} = rh_{amb};\ se_{ci} = se_{amb}$$

Where subscripts ci defines the collector inlet and amb is the ambient. Using the values of the outlet and inlet temperatures of the solar collector, the useful energy gain by the drying air, $\dot{Q}_{uda}$, was determined by **Leon *et al.* (2002)** from equation 3 as:

$$\dot{Q}_{uda} = \dot{m}_{da} C_{pda} (T_{co} - T_{ci}) \qquad \text{Eqn 3}$$

Where T_{ci} and T_{co} refer to the drying air temperatures at the inlet and outlet of the solar collector, respectively. Provided that the psychometric transformation of wet air inside the collector is exclusively a sensible heating, resulting $sh_{co} = sh_{ci}$, and therefore the values of relative humidity (rh_{co}) and specific enthalpy (se_{co}) at the outlet of the air solar collector can be fitted using the psychometric chart.

Determination of the inlet and outlet conditions of greenhouse drying chamber

The setup of the solar drier was assumed to be such that the conditions of drying air at the inlet of the drying chamber were the same as those at the outlet of the solar air heater. This way, the small heat losses that might be developed between the heater outlet and the drying chamber inlet are neglected and subscripts dci defines the drying chamber inlet and ho the heater outlet.

$sh_{dci} = sh_{co};\ T_{dci} = T_{ho};\ rh_{dci} = rh_{ho};\ se_{dci} = se_{ho}$

The values of the specific humidity of the drying air at the outlet of the drying chamber can be calculated as follows (**Midilli and Kucuk, 2003**):

$$sh_{dco} = sh_{dci} + \frac{\dot{m}_{wp}}{\dot{m}_{da}} \qquad \text{Eqn 4}$$

Where sh_{dci} denotes the specific humidity of the drying air at the inlet of the drying chamber and $\dot{m}_{wp}$ is the mass flow rate of the moisture removed from the residues on the tray. The relative humidity and the enthalpy of the drying air at the outlet of the drying chamber were estimated using the psychometric chart program. During the drying process at the tray inside the drying chamber, the heat used can be calculated by using the psychometric chart together with the following equation (**Nikbakht *et al.*, 2013; Prommas *et al.*, 2010 and Lamnatou *et al.*, 2012**):

$$\dot{Q}_{dc} = \dot{m}_{da}(se_{dci} - se_{dco}) \qquad \text{Eqn 5}$$

Exergy analysis

Thermodynamic analysis, particularly exergy analysis, has appeared to be an essential tool for system design, analysis and optimization of thermal systems, including drying systems. Exergy is defined as the maximum amount of work which can be produced by a stream of matter, heat or work as it comes to equilibrium with a reference environment. In the drying industry, the goal is to use a minimum amount of energy for maximum moisture removal for the desired final conditions of the product. Several studies have been conducted on exergy analysis of food drying **Dincer (2002)**. Exergy is a measurement of the maximum useful work that can be done by a system interacting with an environment at a constant pressure and temperature. The exergy was determined based on the following equation (**Celma** and **Cuadros, 2009** and **Fudholi** ***et al.*****, 2014)**:

$$Exergy = \dot{m}C_P\left[\left(T - T_{ref}\right) - T_{ref}\ln\frac{T}{T_{ref}}\right] \qquad \text{Eqn 6}$$

DRYING PROCESS PERFORMANCE ANALYSIS

Instantaneous moisture content (Mt)

To evaluate the performance of each drying unit, a methodology proposed by **Leon** ***et al.*** **(2002)** was used in this study. The instantaneous moisture content (M_t) on dry basis at any time can be calculated from the following equation:

$$M_t = \left[(M_o + 1)\,{}^{W_t}/_{W_o}\right] - 1 \qquad \text{Eqn 7}$$

Drying rate

The drying rate was found by the decrease of the water concentration during the time interval between two subsequent measurements divided by this time interval. The drying rate (DR) was therefore expressed by the following equation by (**Banout** ***et al.*****, 2011)**:

$$DR = \frac{Mw}{Mds.t} \qquad \text{Eqn 8}$$

Drying efficiency

To evaluate the drying process evolution of each solar drier overall system, the drying efficiency (ηd) is used. The efficiency of a solar drying system is a measure of how effectively the input energy to the drying system is used in drying product. System efficiency for the forced convection solar driers needs to take into account the energy consumed by the fan. The following equation is then used by (**Banout** ***et al.*****, 2011)**:

$$\eta_d = \frac{M_{w}\,\Delta Hl}{IAT+PF} \qquad \text{Eqn 9}$$

RESULTS AND DISCUSSION

Figure 4 shows the daily average available solar radiations flux. Solar radiation started from 762.1W/m^2 at (10:00AM, 1drying hour) expressed as (daytime, drying hour) and has its maximum value of 858.76W/m^2 at (12:00PM, 3 drying hour) after that it decreased until reached to 407.85W/m^2 at (3:00PM, 6 drying hour) during drying experiment. Figure 5 shows the measured drying air temperature during the drying experiment at three different drying air velocities of 0.5, 1.0 and 1.5m/s. The gradually increasing in the temperature of the drying chamber was affected by the increasing of ambient air temperature and solar collector air temperature because of increasing solar radiation until it reached its peak and then begin to decrease, at drying air velocities of 0.5, 1.0 and 1.5m/s. The drying air temperatures of the drying chamber were of 60.8, 57.2 and 47.5°C at (12.00PM, 3dh) for drying air velocity of 1.5, 1.0 and 0.5m/s, respectively. It can be noticed that the highest drying air temperature inside the drying chamber was achieved at drying air velocity of 1.5m/s due to the distribution method of hot and cold air inside air column of the solar collector was as layers (thermo stratification). The highest air temperatures were concentrated at top layers and boundary layers of collector walls. On the other side, the bottom layers have the lowest air temperature. Air duct located at solar collector bottom for drying air transferring to drying chamber. The initial suction of drying air was from the bottom layers, the lowest air temperatures. With the increasing of drying air velocity, the suction rate from the collector increased as follows, which causes a mixture among air layers generates a circulation inside the collector, more circulation gives higher air temperature. Drying air temperature started from 45, 46.9 and 55°C and ended at 29.5, 28.1 and 39.4°C at drying air velocities of 0.5, 1.0 and 1.5m/s, respectively. Figure 6 illustrates the air relative humidity has its maximum value of 65.7% at (4:00PM, 7dh) and drying air temperature of 20.7°C and its minimum value of 43.1% at (2:00PM, 5dh) and drying air temperature of 23.9°C at drying air velocity of 0.5m/s. The same behavior was obtained at drying air velocity of 1.0m/s as ambient air temperature increases to 29.8°C at (12:00PM, 3dh) its air relative humidity decreases to 44.1% and as ambient air temperature decreases to 22.7°C at (5.00PM, 8dh) its relative humidity increases to 61.5%. Similarly at drying air velocity of 1.5 m/s, as ambient air temperature increases to 32.2°C at (12:00PM, 3dh) its relative humidity decreases to 37.2% and as ambient air temperature decreases to 23.4°C at (5.00PM, 8h) its relative humidity increases to 50.6%.

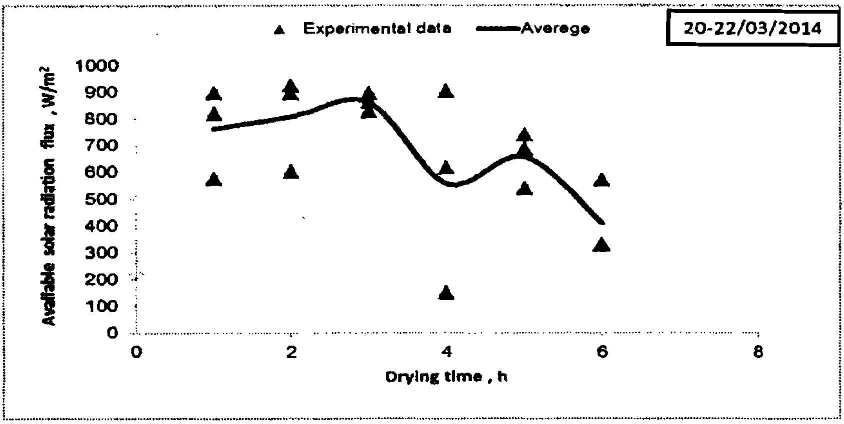


Figure 4. Available solar radiation flux as a function of drying time during the drying experiment

Figure 7 shows drying air capacity based on absolute humidity difference and based on temperature difference variations of the solar collector and drying chamber as a function of drying time. The highest values of drying air capacity were achieved at daytime period from (12.00PM, 3dh) to (2.00PM, 5dh) for all the experimented drying air velocities. The drying air capacity based on absolute humidity and temperature difference are raised from 0.000219kg water/m^3 dry air and 4.92°C of the ambient air temperature to 0.00093kg water/m^3 drying air and 6.53°C, 0.0058kg water/m^3 dry air and 5.93°C to 0.00072kg water/m^3 dry air and 6.62°C and 0.00128kg water/m^3 dry air and 8.93°C to 0.00310kg water/m^{3}dry air and 11.22°C, respectively at drying air velocities of 0.5, 1.0 and 1.5m/s, respectively. The drying air velocity of 1.5m/s achieved the highest values of drying air capacity due to thermo stratification phenomena. Once the drying air enters the drying chamber, the drying air capacity decreases from 0.00534 to 0.00455kg water /m^3 dry air and from 0.00324 to 0.00283 kg water /m^3 dry air for drying air velocities of 0.5 and 1.0m/s, respectively. These losses are due to moisture migration from the dried product. But at drying air velocity of 1.5m/s, the drying air capacity of 0.00751kg water /m^3 dry air is still raising inside drying chamber because

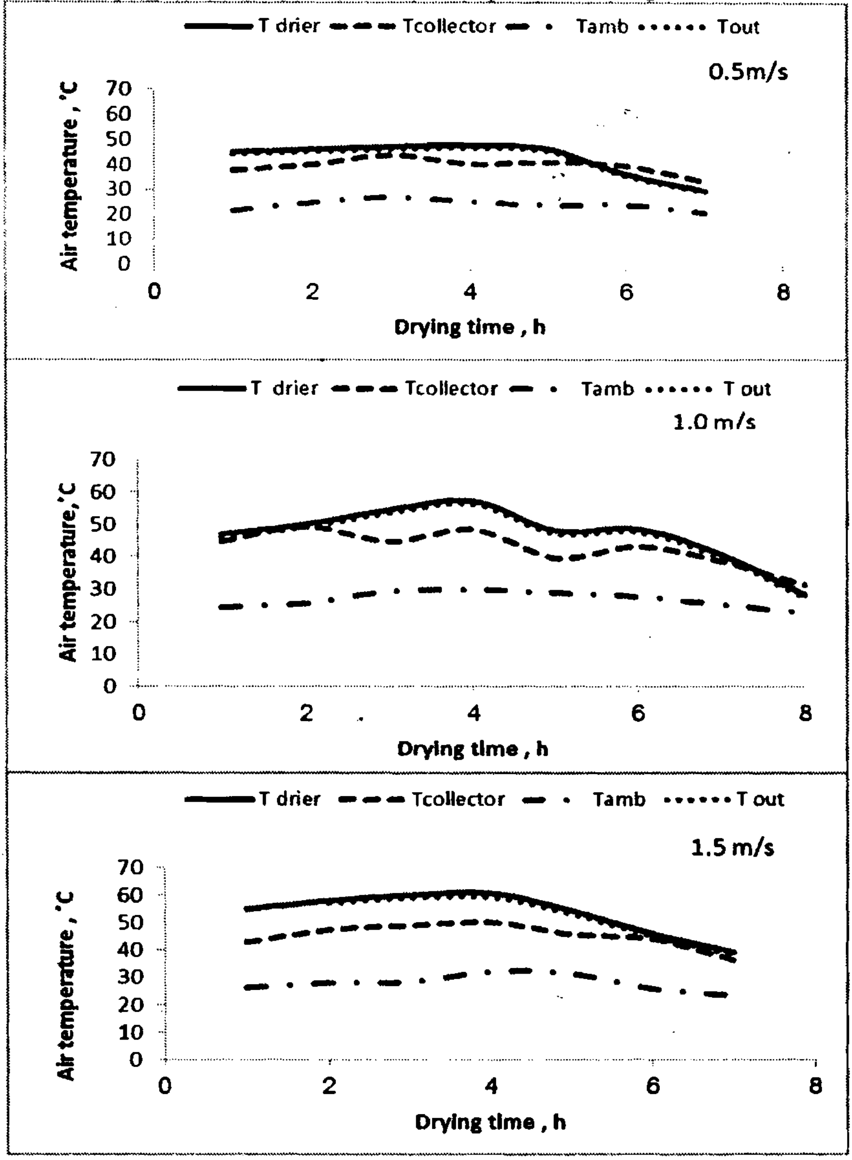


Figure 5. Air temperature as a function of drying time during the drying experiment at different drying air velocities

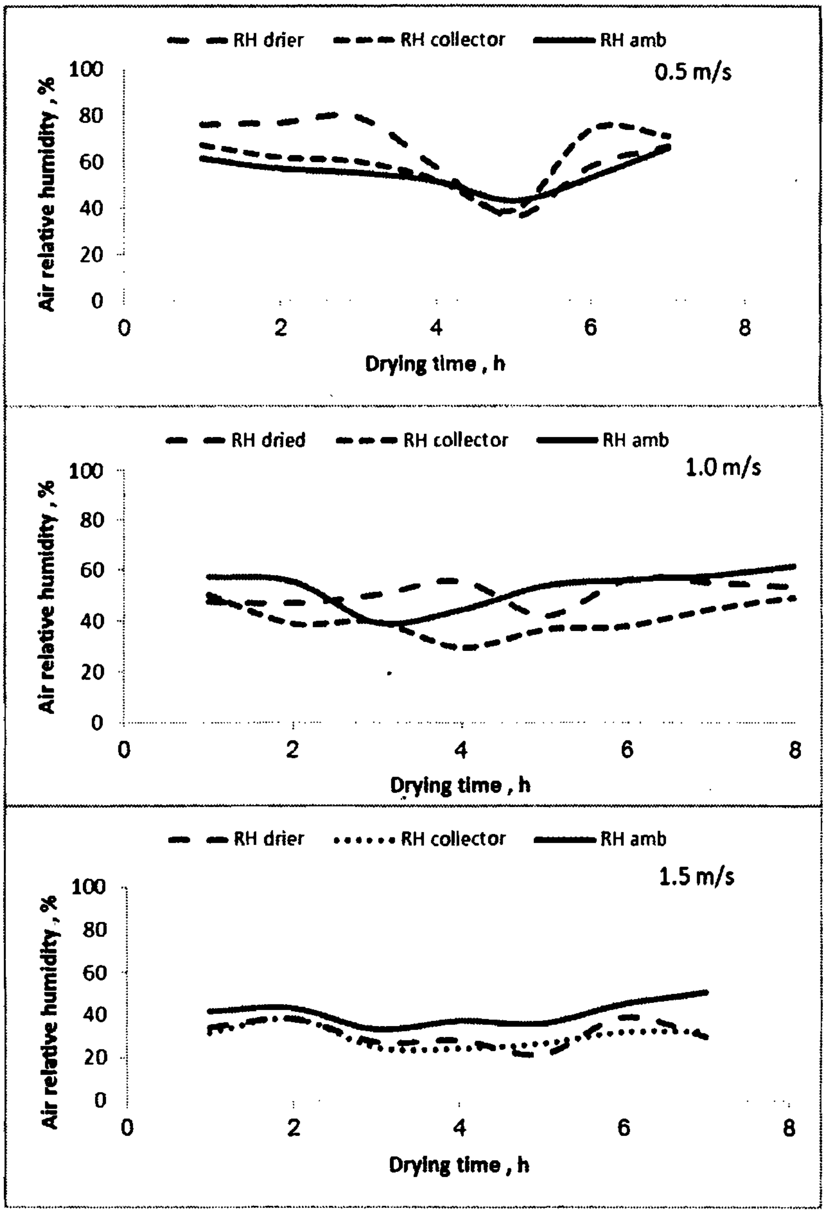


Figure 6. Air relative humidity as a function of drying time during the drying experiment at different drying air velocities

the drying air doesn't reach stability at the moment of entering drying chamber (ranged from 0.008123 to 0.008324kg water /m^3 dry air) according to drying chamber air temperature. The specific enthalpy of the semi-cylindrical solar drier was higher than that of the two others (ambient and collector). Also the specific enthalpy inside the solar collector has higher values than that of the ambient specific enthalpy at all drying air velocities. Figure 8 shows the maximum values of specific enthalpy of 192.53, 229.47 and 159.41kJ/kg inside the solar drier at 0.5, 1.0 and 1.5m/s, respectively. While, the maximum values of specific enthalpy inside the solar collector were of 133.93, 126.49 and 100.41kJ/kg at 0.5, 1.0 and 1.5m/s, respectively. Ambient air specific enthalpy had the lowest values of 58.57, 63.14 and 61.06 kJ/kg at 0.5, 1.0 and 1.5m/s respectively. In general, specific enthalpy of drying air increases by increasing drying air velocity. Figure 9 shows the heat energy gained by the solar collector at drying air velocity of 0.5m/s ranged from 70.33 to 56.2W during the daytime period from (11:00AM, 2dh) to (4:00PM, 7dh). The maximum heat energy gained of 78.67W was obtained at (12:00PM, 3dh). The heat energy gained by the solar collector ranged from 216.95 to 119.33W during the daytime from (11:00AM, 2dh) to (4:00PM, 7dh) at drying air velocity of 1.0m/s. The maximum heat energy gained of 216.95W was obtained at (11:00PM, 2dh). The heat energy gained by the solar collector ranged from 287.51 to 174.57W at daytime from (11:00AM, 2dh) to (4:00PM, 7dh) at drying air velocity of 1.5m/s. The maximum heat energy gained of 287.51W was obtained at (11:00PM, 2dh). Figure 10 shows that at (1:00PM, 4dh) at drying air velocity of 0.5m/s and at (10:00AM, 1dh) to (12:00PM, 3dh) at drying air velocity of 1.0m/s, the exergy summation is -0.3566 kJ/kg drying air and ranged from -0.5801 to -0.055 kJ/kg drying air, respectively. When the exergy summation has a minus sign, the drying process uses this amount from the exergy carried by drying air from the solar collector and if the exergy summation is positive, the drying process doesn't need any exergy stored in the drying air but vice versa it adds exergy to the drying air and only uses some amount of the exergy gained by drying chamber, and hence the solar collector is not needed at these moments. Also it can be concluded that when ambient air temperature increases the exergy losses increases.

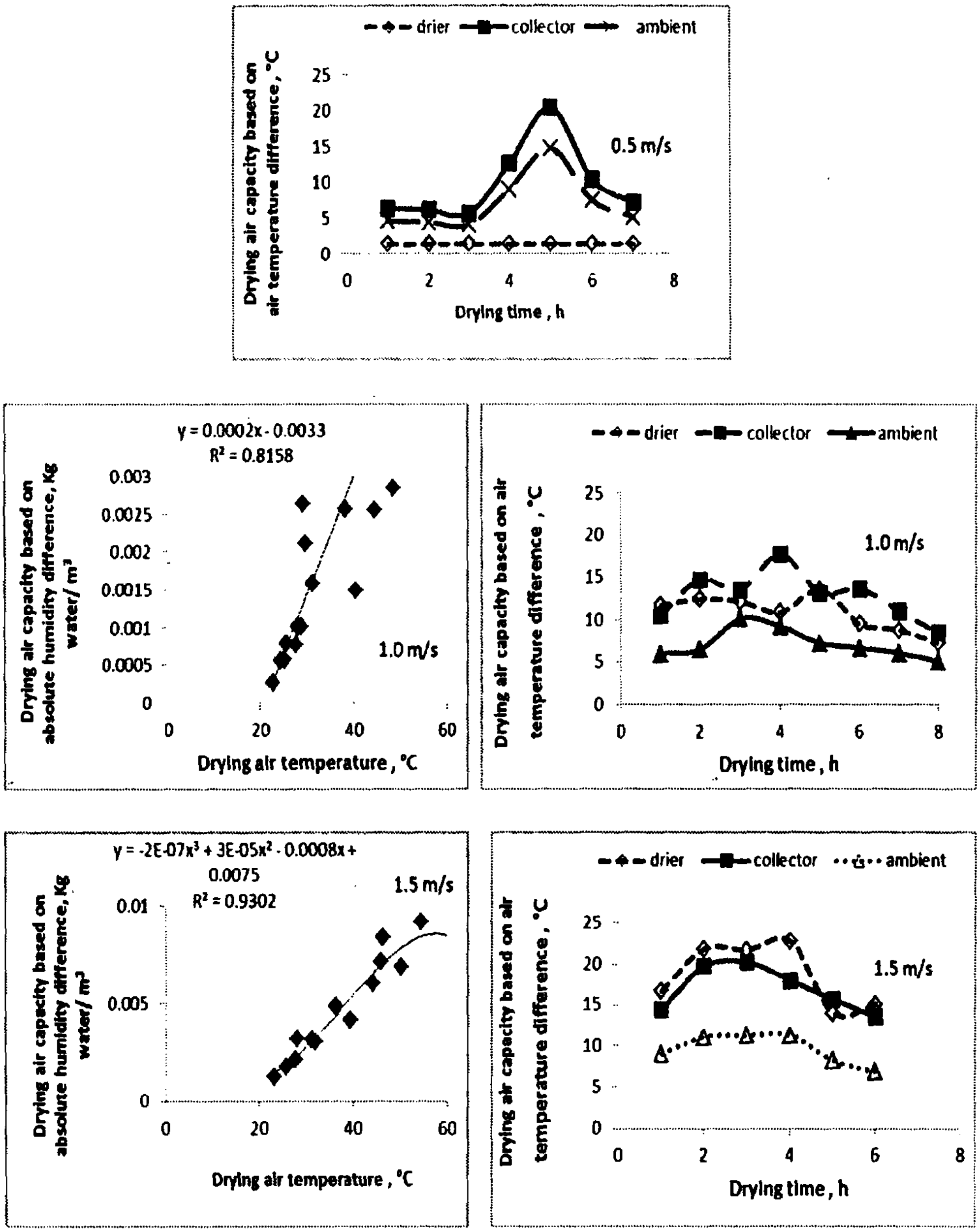


Figure 7. The effect of drying air temperature on drying air capacity based on air absolute humidity and air temperature differences at different drying air velocities

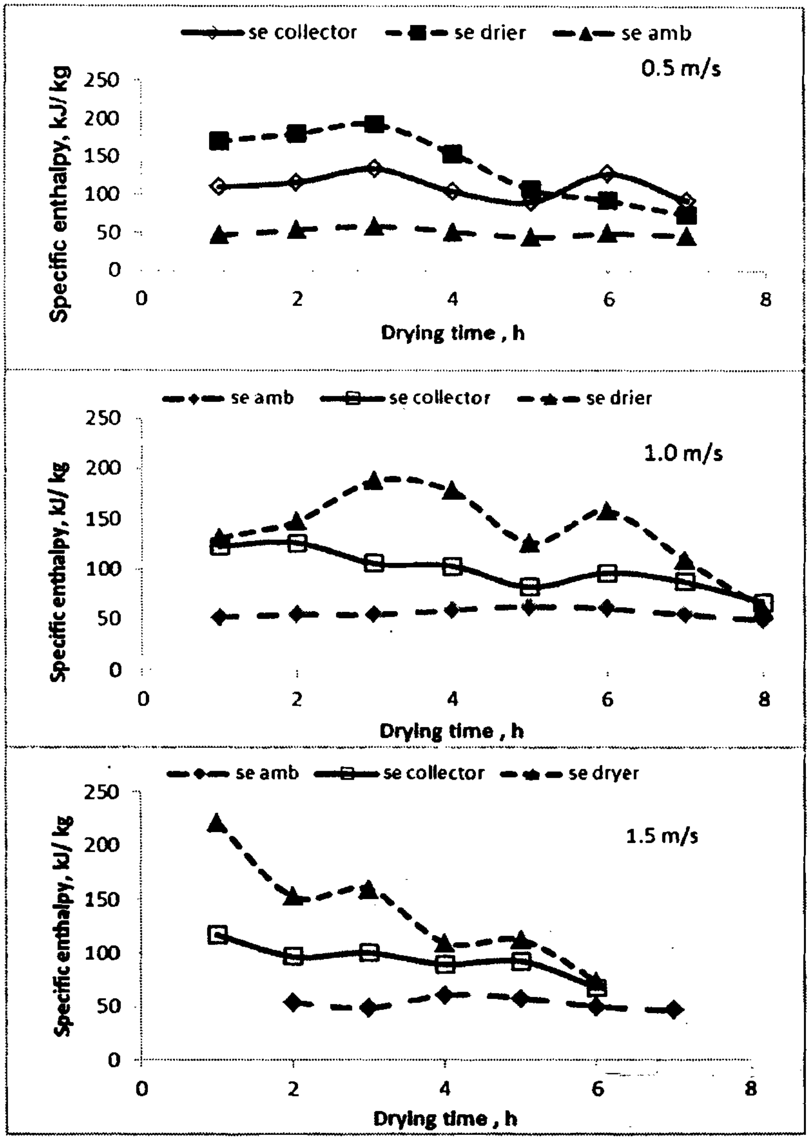


Figure 8. Specific enthalpy of the drying air as affected by drying time at different drying air velocities

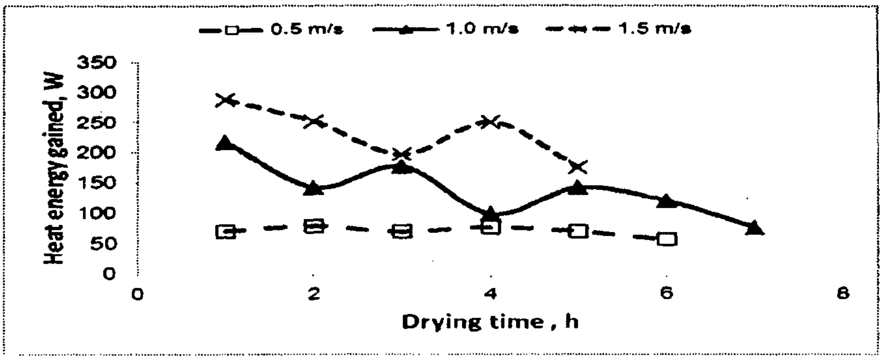


Figure 9. The heat energy gained by the solar collector as a function of drying time at different drying air velocities

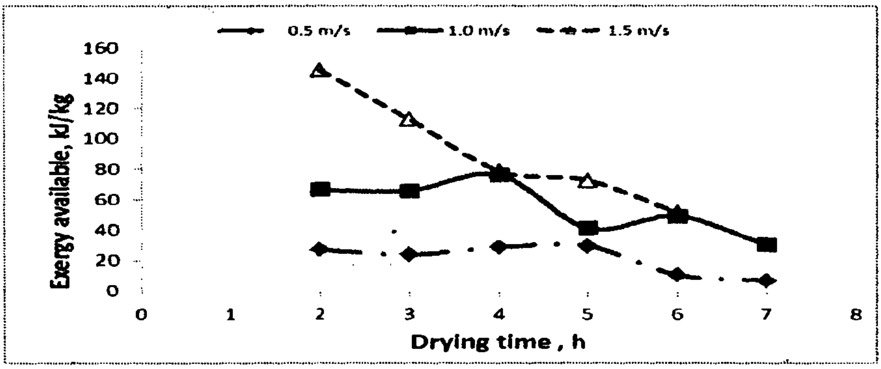


Figure 10. The exergy available as a function of drying time at different drying air velocities

It is observed from Figure 11 that, there are three different drying rate curves; the drying rate curve profile at drying air velocity of 0.5m/s is higher than that of 1.0 and 1.5m/s. In case of peas residues chopping length of 6 cm and bed depth of 5cm at daytime (12:00PM, 3dh), moisture content was high at the beginning of the drying process and lead to condensation at the drier atmosphere from residues resulting in reducing drying rate to a negative value and at daytime of (2:00PM, d5h), it increases until it reached 48.44kg water /(kg dry matter. min) and then began to decrease with the time until arrived at 30.21kg water /(kg dry matter. min) at (5:00 PM, 8dh). The same behavior was found at drying air velocities of 1.0 and 1.5m/s.

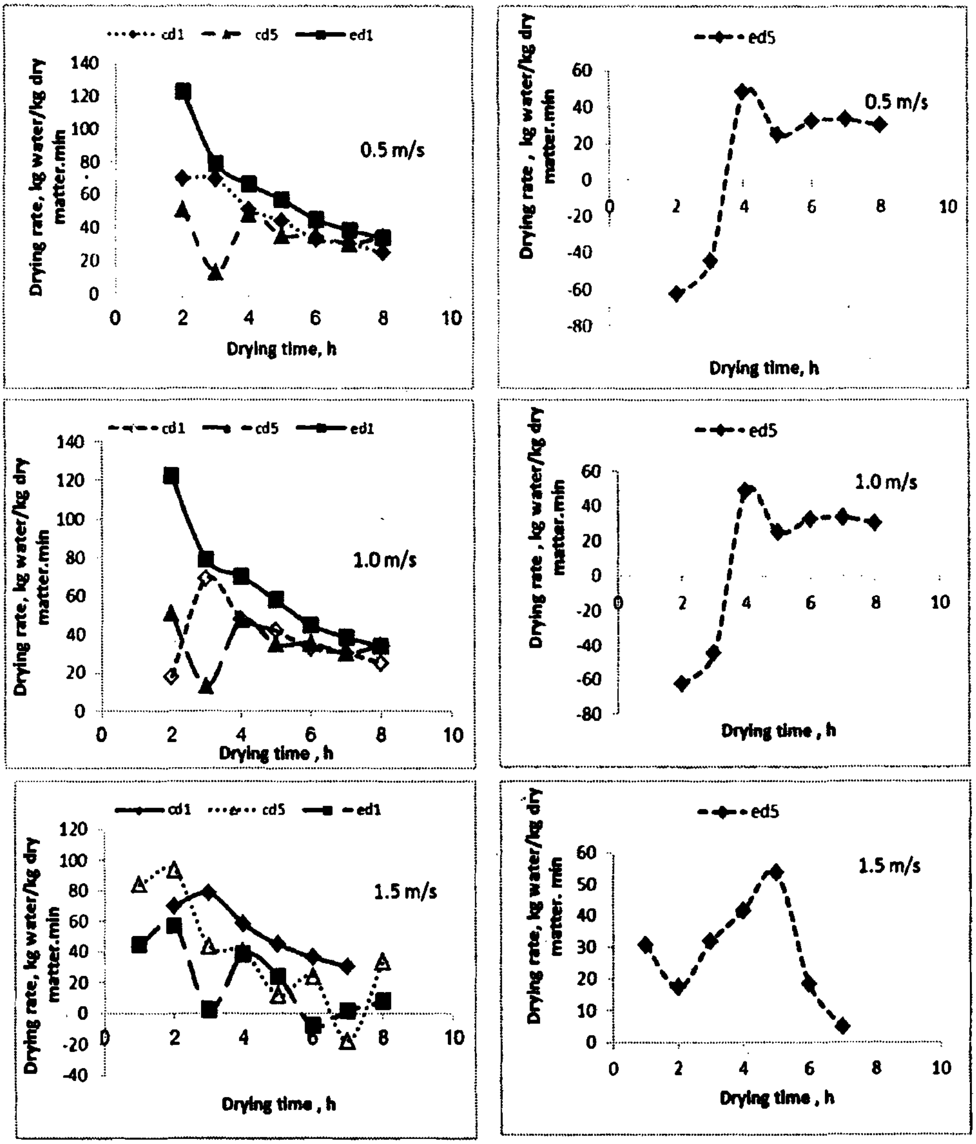


Figure 11. Evolution of drying rate as affected by drying time at different drying air velocities, different chopping lengths and different drying bed depths

At drying air velocity of 0.5m/s, the drying process started at (11:00AM, 2dh) and extended to increase to (5:00PM, 8dh). Figure 12 shows the reduction in drying efficiencies is due to the solar energy starts to be lower and the amount of heat energy stored in the drier and product is still used in evaporation. Also at drying air velocity of 1.0m/s, the drying efficiencies are starting lower with values of 2.55 to 11.36%, and decrease to -29.8 at (4:00PM, 7dh) due to condensation and gaining moisture from the ambient air. The acquisition of solar energy from the ambient air as well as the temperature inside the greenhouse drier and waste heat itself led to increase the drying efficiency. The same behavior was found at drying air velocity of 1.5m/s. It was noticed that the drying air velocity of 1.5m/s achieved the highest drying efficiency of 68.28% at (12:00PM, 3dh). The productivity of the solar drier was of 1.186kg dried peas residues/m^2 of the experimented drier box per day. The drying rate was selected as the most effective indicator in the current study and can be estimated at the optimum drying air velocity of 1.5m/s as follows:

$$DR=388.0921-6.3796T+0.248SR+2.415dep-11.34CL-0.213Se-0.171MC+0.285AC-1.395Eng+2.087Exg \quad \mathbf{R^2=0.8094} \quad \textbf{Eqn 9}$$

Where;

DR: Drying rate, Kg water/(kg dry matter. min)

MC: Moisture content, kg water/ kg dry matter %db.

CL: Chopping length, cm

T: Temperature of drying chamber, °C

SR: Solar radiation, W/m^2

AC: Drying air capacity based on temperature difference, °C

Se: Specific enthalpy, KJ/kg

Eng: Energy, W

Exg: Exergy, kJ/kg

Dep: Drying bed debth, cm

This developed equation is valid only within the range of application.

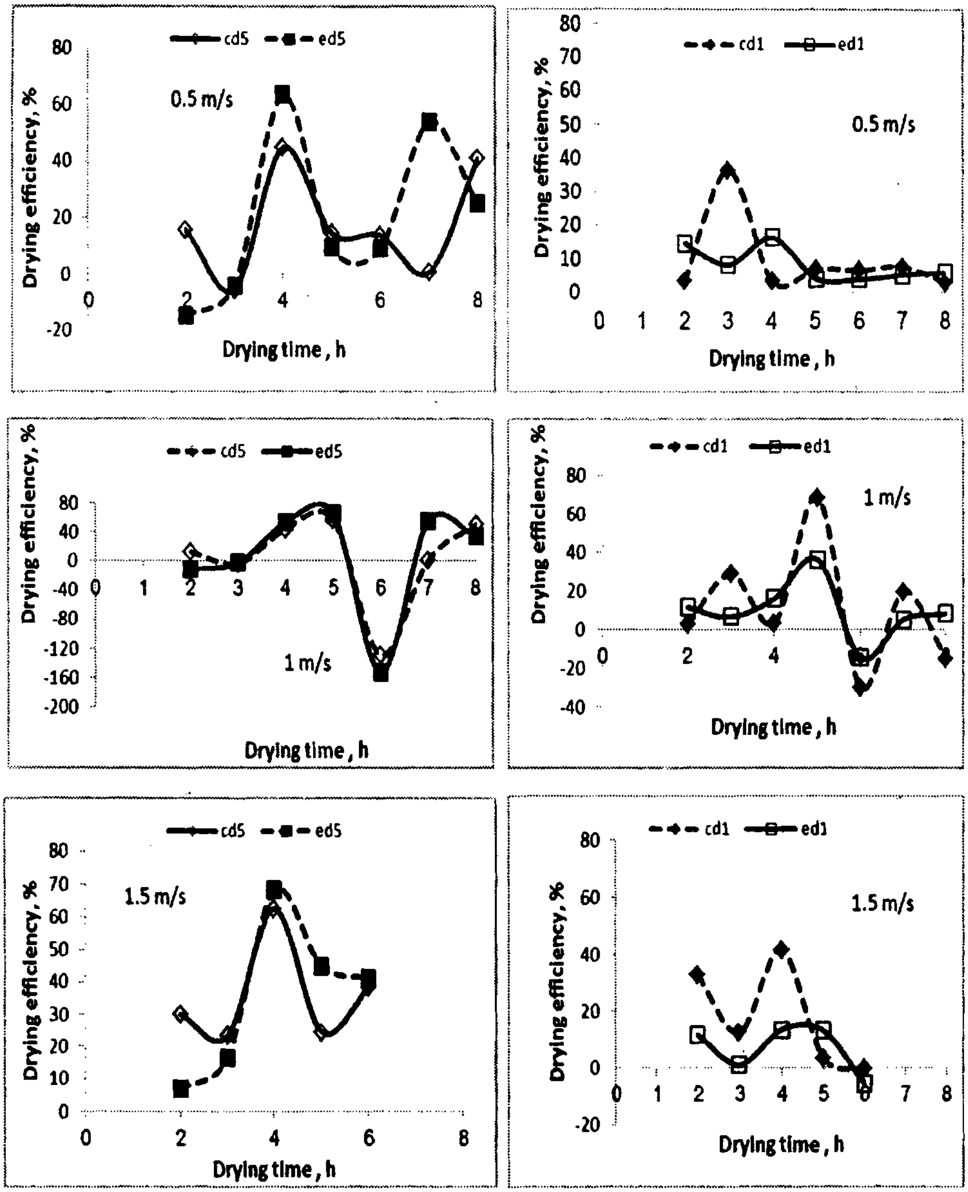


Figure 12. Evolution of drying efficiency with the drying time at different drying air velocities, different chopping lengths and different drying bed depths

Chemical composition of peas residues is presented in Table 1. It is revealed that crude protein, ash, NFE and ether extract increased as a dry matter.

Table 1. Chemical composition of fresh and dried peas residues

Item	Crude fiber, cf	Crude protein, cp	Ether extract, EE	Ash	NFE
Fresh peas residues	47.6	1.88	0.24	2.5	8.34
Dried peas residues	23.8	9.4	1.2	12.5	41.7

CONCLUSIONS

The drying air velocity of 1.5m/s was the most effective in increasing drying air capacity because of (Thermo stratification) and achieves the highest drying rate compared to 0.5 and 1.0m/s. The drying air velocity of 1.5m/s achieved the highest exergy of 144.94kJ/kg drying air and has the highest heat energy gained of 287kJ. The moisture content decreases at drying air velocity of 1.5m/s, ensuring the highest drying rate of 0.0938kg water/(kg dry matter. min) for peas residues drying bed depth of 5cm and peas residues chopping length of 3cm. The maximum values of specific enthalpy at drying air velocities of 0.5, 1.0 and 1.5m/s were of 192.53, 229.47 and 159.41kJ/kg inside the drying chamber respectively. In contrast ambient air specific enthalpy had the lowest values of 58.57, 63.14 and 61.06kJ/kg at 0.5, 1.0, 1.5m/s, respectively. The drying air velocity of 1.5m/s achieved the highest drying efficiency of 68.28% at (12:00PM, 3dh). Peas residues chopping length of 6cm and drying bed depth of 5cm were the most suitable residues distribution on the drying trays. The productivity of the solar drier was of 1.186kg dried peas residues/m^2 of the experimented drier box per day. The highest drying rate of 0.0938kg water/ (kg dry matter. min) has been achieved at the optimum operating conditions as drying air velocity of 1.5 m/s and chopping length of 3cm and drying bed depth of 5cm from peas residues.

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الملخص العربى

هندسة إنتاج العلف بواسطة التجفيف الشمسى لمخلفات محاصيل الخضر

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انخفضت مصادر الغذاء للإنتاج الحيوانى مما أثر على الاستهلاك الأدمى . ازدادت المشكلة فى هذة الأيام نتيجة اتجاة الحكومة الى زيادة انتاجية محاصيل الحبوب الرنيسية مثل القمح فى الشتاء والأرز والذرة فى الصيف مما يترتب علية التنافس على الرقعة الزراعية فى فصل الصيف والشتاء مما أدى الى زيادة اسعارالأعلاف التقليدية خاصة فى الشتاء مثل البرسيم. تعتبر مخلفات المحاصيل والخضر من اهم المخلفات الزراعية وذلك لان قيمتها الغذائية عالية ومن ضمن هذة المخلفات مخلفات البسلة وتعد مصر سادس دول العالم فى انتاج البسلة حيث تنتج ١٦٩١٢٢ طن فهى متوفرة فى مصر فى فصل الصيف ومن السهل استخدامها كعلف للحيوان حيث ارتفاع القيمة الغذائية لها. يهدف هذا البحث إلى دراسة إمكانية توفير أعلاف بديلة و غير تقليدية فى فصل الشتاء جنباً الى جنب مع فصل الصيف عن طريق دراسة تجفيف مخلفات البسلة (العرش). ودراسة إمكانية استغلال الطاقة الشمسية فى شهر مارس عام ٢٠١٤م لتجفيف مخلفات البسلة عن طريق إستخدام صوبة نصف اسطوانية تحت سرعات هواء تجفيف مختلفة وظروف تحميل مختلفة. تم دراسة المتغيرات والعناصر الأتية:

- تأثير سرعات هواء التجفيف المختلفة على تطور عملية التجفيف من خلال معدل التجفيف وكفاءة التجفيف والطاقة الحرارية المكتسبة وسعة هواء التجفيف
- دراسة تأثير أطوال القطع على كفاءة عملية التجفيف
- دراسة خواص هواء التجفيف
- دراسة سلوك عملية التجفيف مع تغييرعمق طبقة التجفيف عن طريق:

أ- المحتوى الرطوبي على أساس رطب وعلى أساس جاف

ب- معدل التجفيف

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تم قياس سعة هواء التجفيف (الفرق بين الرطوبة المطلقة أو درجة الحرارة الإبتدائية والرطوبة المطلقة أو درجة الحرارة عند التشبع الأدياباتيكي) عند ثلاثة مناطق (للوسط المحيط كظروف أولية، داخل المجمع الشمسي، غرفة التجفيف). تم الحصول على مخلفات البسلة طازجة من الحقل ونقلها إلي مكان التجربة بمركز ميكنة الأرز بميت الديبة محافظة كفر الشيخ حيث كان المحتوي الرطوبي الابتدائي (٧٢٪ علي اساس رطب) وتم تحضير وتجهيز المخلفات لعملية التقطيع (٣، ٦ سم) وعلي عمق (١، ٥ سم). تم تصنيع مجفف شمسى من نوع الصوبة نصف الإسطوانية في مركز ميكنة الأرز بميت الديبة، محافظة كفرالشيخ، فى تجارب التجفيف الشمسي لمخلفات البسلة الزراعية خلال شهر مارس لعام ٢٠١٤م. تم استخدام مجمع شمسى من نوع greenhouse سعة الهواء فيه ٨٢,٤ م^{٣}. تم توصيل المجفف الشمسى بالمجمع الشمسى ،وتم استخدام طولين لتقطيع مخلفات البسلة وهي ٣، ٦ سم وتوزيعها داخل صوانى التجفيف بعمق ١ ،٥ سم بينما تم استخدام سرعات هواء تجفيف مختلفة(٥ ,٠، ١,٠ ، ١,٥ م/ث). تم تحليل البيانات وفيما يلي عرض لأهم النتائج التى تم التوصل إليها :

١- سرعة هواء التجفيف ١,٥ م/ث هى أكثر السرعات تأثيراً على زيادة سعة هواء التجفيف وذلك بسبب زيادة طاقة السريان والتى تتناسب طردياً مع مربع السرعة ، فيزداد سعة هواء التجفيف بزيادة سرعة هواء التجفيف.

٢- سرعة هواء التجفيف ١,٥م/ث تحقق أعلى طاقة مكتسبة ٢٨٧ كيلو جول على عكس السرعات (٥ ,٠ ، ١,٠م/ث) والتى تحقق طاقة مكتسبة أقل.

٣- محصلة الطاقة الشغالة داخل غرفة هواء التجفيف تدل على مدى ملاءمة المجمع الشمسي. تم التوصل إلى أن غرفة التجفيف لا تحتاج إلى المجمع الشمسي إلا فى الفترة من الساعة العاشرة صباحاً وحتى الثانية عشرة ظهراً وبعد ذلك لاتحتاج المجمع الشمسى وذلك لوجود طاقة حرارية مخزنة وأيضا الإشعاع الشمسى الساقط على المجفف.

٤- المحتوى الرطوبي ينخفض عند سرعة هواء تجفيف ١,٥م/ث محققاً أعلى معدل تجفيف ٠,٠٩٣٨كج ماء/دقيقة لعمق طبقة تجفيف ٥سم وطول قطع ٣سم.

٥- معدل التجفيف يتأثر بعدة عوامل مثل الإنثالبيا النوعية، سعة هواء التجفيف، كمية الحرارة المكتسبة، الطاقة الشغالة، طريقة توزيع المخلفات على صواني التجفيف، و أخيراً المحتوى الرطوبى. كل هذه العوامل لها تأثير على معدل التجفيف وتم تقدير معدل التجفيف عند أعلى سرعة هواء تجفيف ١,٥م/ث وتم استخدام التحليل الإحصائي المتعدد الإنحدار وتم الحصول على المعادلة الأتية:

$$DR = 388.0921-6.3796T+0.248SR+2.415dep-11.34CL-0.213Se-0.171MC+0.285AC-1.395Eng+2.087Exg \qquad R^2 =0.8094$$

حيث

DR معدل التجفيف، كج ماء/ كج مادة جافة. دقيقة

AC سعة هواء التجفيف، درجة منوى

Se الانثالبيا النوعية، كيلوجول/كج

MC المحتوى الرطوبى لعرش البسلة، ٪ أساس رطب

SR الإشعاع الشمسى الساقط، وات/م^{٢}

T درجة حرارة هواء غرفة التجفيف، درجة منوية

CL طول قطع المخلفات، سم

Dep عمق طبقة التجفيف، سم

Eng كمّية الطاقة المكتسبة، وات

Exg الطاقة الشغالة المتاحة ، كيلوجول/كج

٦- كفاءات التجفيف لطرق توزيع المخلفات على صوانى التجفيف من ساعة تجفيف ١٠-١٥ ساعة، أعلى كفاءة تجفيف كانت لطول قطع المخلفات ٦سم مع عمق طبقة تجفيف ٥سم عند سرعة هواء تجفيف ١,٥م/ث.

٧- بلغت الإنتاجية اليومية للمجفف الشمسى ١,١٨٦كج مخلفات بسلة مجففة/ م^{٢} من صندوق المجفف التجريبى. تم الوصول الى أعلى معدل تجفيف ٠,٠٩٣٨ كج ماء/(كج مادة جافة. دقيقة) عند ظروف التشغيل المثلى عند سرعة هواء التجفيف ١,٥م/ث وطول قطع مخلفات البسلة وعمق طبقة التجفيف٣، ٥سم على التوالى.