DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A SOLAR DRYING UNIT OF BASIL LEAVES

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ABSTRACT

Two similar solar drying units were designed, constructed and evaluated for drying basil leaves (Ocimum basilicum L.) as a medicinal and aromatic plant at initial moisture content of 590.73% (d.b) or 85.52% (w.b) under Fayoum conditions by using heated air. Each drying unit consists of a flat-plate solar collector, which oriented and tilted with an optimum tilt angle and attached with drying chamber. The drying experiments were carried out to examine the effect of basil leaves thicknesses (2, 4 and 6 cm) and airflow rate (0.015 and 0.025 m³.sec⁻¹) on the basil leaves drying rate. The obtained results indicated that the daily average total solar radiation flux incident on the tilted solar collector surface (29.30 MJ. m⁻².day⁻¹) was greater than that incident on the horizontal surface (24.30 MJ.m⁻².day⁻¹) by 24.58%. The output higher air temperatures were obtained at the lower airflow rate whereas; the energy gained to the air from the solar collector was relatively higher at the higher airflow rate as compared with the lower airflow rate. Consequently, the solar collector with the higher airflow rate increased the overall thermal efficiency by 5.46% as compared to the lower airflow rate. The moisture content of dried basil leaves was strongly affected by the basil leaves thickness and the airflow rate. The final moisture content of dried basil leaves ranged from (11.52% to 14.58% d.b) depending on the drying temperature cycle. Very small changes were observed in the colour and shape of heated-air dried basil leaves as compared to that dried at direct sun rays. The essential oil contents of dried basil leaves were slightly higher for the drying unit with the higher airflow rate as compared with the corresponding values obtained from the drying unit with the lower airflow at all basil leaves thicknesses.

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While on Contrast, total chlorophylls contents were slightly higher for the drying unit with the lower airflow rate as compared with the corresponding values obtained from the drying unit with the higher airflow at all basil leaves thicknesses. Effect of the individual variables (airflow rate, basil leaves thickness, moisture removed, and their interactions) on the drying rate was statistically analyzed. Under the conditions of this study, the optimum depth to dry basil leaves by using heated air is 4 cm.

INTRODUCTION

The medicinal and aromatic plants are cultivated in all over the world especially in Egypt for both local consumption and export. sweet basil is one of the most important aromatic plants cultivated in Fayoum Governorate (especially at Abchway district), Egypt. **Schenkel *et al.* (2003)** indicated that the use of medicinal plants is part of a competitive market, which includes pharmaceuticals, food, cosmetics, and perfumery markets. In pharmaceuticals, plant extracts are especially relevant due to the use of their active substances for medicine development and as source to obtain adjuvant. **CAGMC (2003)** reported that the cultivated area of medicinal and aromatic plants in Egypt is about 1091 feddans, producing about 1951 ton/year from green plants and 29.26 ton essential oil. Many farmers in Egypt still using natural sun and wind to dry aromatic plants, but low quality and high losses occur because during this drying method, the aromatic plants are not protected from dust, rain, birds, and insects**. Bowles (2004)** mentioned that in all regions of the world, the history of peoples shows that medicinal and aromatic plants have always occupied an important place in medicine, the composition of perfumes, food and in cooking. **Bozin *et al.* (2006)** indicated that recently, there has been much research into the health benefits conferred by the essential oils found in basil. Scientific studies in vitro have established that compounds in basil oil have potent antioxidant, antiviral, and antimicrobial properties, and potential for use in treating cancer. **Tohti *et al.* (2006)** reported that basil has been shown to decrease the occurrence of platelet aggregation and experimental thrombus in mice. It is traditionally used for supplementary treatment of stress, asthma and diabetes in India.

Pierce and Thompson (1980) indicated that the airflow rate is the most important factor in the design and operation of low temperature drying systems regardless of whether natural air or heated air is used. **Muhlbauer, (1986)** mentioned that sun drying is still the most common method used to preserve agricultural products in most tropical and subtropical countries. However, being unprotected from rain, wind borne dirt, dust, and infestation by insects, rodents and other animals. Sun dried product may be seriously degraded to the extent that sometimes it becomes inedible, and the resulted loss of food quality in the dried product may have adverse economic effects on domestic and international markets. So that, the introduction of solar dryers in developing countries can reduce crop losses and improve the quality of dried product significantly compared with traditional drying method**. PaTil and Ward (1989)** classified solar drying process into three modes on the basis of drying air temperatures namely: (a) natural air drying, (b) supplemental heated air drying and (c) heated air drying. **Hazra *et al.* (1990)** indicated that drying medicinal and aromatic plants in direct sunlight produced 24% less vapor than required during distillation. **Okos *et al.* (1992)** indicated that the main aim of drying products is to allow longer periods of storage, minimize packaging requirements and reduce shipping weight.

Hassanain (2004) dried medicinal plants (henna, rosemary and marjoram) using unglazed transpired solar dryer. He indicated that the average efficiency of the solar dryer used was varied due to the type of the medicinal plants and the weather conditions of the location. **Abdel-Galil and Tarhuni (2005)** used solar dryer to dry peppermint (*Mentha Peperita*) under Tripoli conditions, Libya by using heated air. They indicated that increasing the airflow rate and the peppermint depth, reduced the drying time by 15 to 20%. The final moisture content was 6.2 % (d. b.) and 6.8% (d. b.) at the airflow rates of 0.015 and 0.025 m^3/s, respectively. **Oztekin and Martinov (2007)** indicated that drying of aromatic and medicinal plants must meet the following requirements: (1) Moisture content has to be brought down to be at an equilibrium level that is defined for certain relative air humidity and temperature. This is defined as storage condition by standards; (2) minimum quality reduction in terms of active ingredients, color, flavor and aroma; and (3) microbial count must be below the prescribed limits. **Arafa (2007)** indicated that

the drying method of sweet basil leaves gave the average drying rates of 43.4%, 47.4% and 59.4% (d.b/hr) for drying periods of 12, 11 and 9 hr. with an average drying air temperatures of 35, 40 and 45 ^{o}C) respectively. The total chlorophyll of 84, 64 and 48 mg/100 grams of the samples were also obtained, respectively. The volatile oil percentages for the three different drying air temperatures were 88.2, 84.6 and 78.9 %, respectively. **Kadam *et al.* (2011)** investigated the effect of different drying conditions on kinetics of basil leaves, the laboratory models of tunnel and tray dryers were employed and air temperatures of 55, 60 and 65°C were considered for the drying. Drying of basil leaves prominently occurred in falling rate period and it was found that basil leaves dried faster in tray dryer. The effective moisture diffusivity (D_{eff}) of basil leaves increased with the increase in drying air temperature. The D_{eff} values were higher for tray dryer than those dried in the tunnel dryer. Effective moisture diffusivity of basil

leaves ranged from 2.65 x 10^{-10} to 5.69 x 10^{-10} m^2/s. **Shahi *et al.* (2014)** investigate the influence of different drying methods (Sun, Solar and vacuum drying) with different drying air temperature (55, 60 and 65°C) on activation energy kinetics of basil leaves. They concluded that the increase in drying air temperature decreased the drying time in both the drying methods while, basil leaves dried faster in solar dryer.

Yousif *et al.* (1999) used conventional hot air or the vacuum-microwave dryers to study the effect of the basil leaves drying method on the relative abundance of major flavor volatiles, rehydration rate, color, and structural integrity of the plant. Vacuum microwave dehydrated basil yielded approximately 2.5 times the linalool and 1.5 times the methylchavicol of the air-dried samples. **Ertekin and Yaldiz (2004)** reported that the drying process should be undertaken in closed equipment to improve the quality of the final product. In an another study, dried basil leaves were evaluated for retention of some volatile compounds using both conventional hot air (50, 60 and 70°C) and low-pressure superheated steam (LPSS) dryers. The LPSS drying proved to be better in terms of the aroma compounds content. **Özcan *et al.* (2005)** reported that basil can be oven dried (at 50 °C) to 17.31% moisture content after 15 h and can be sun dried (temperatures between 30 and 35 ^{o}C) to 23.79% moisture content after 28 h. They also, indicated that the mineral content of oven dried herbs was

higher than sun dried herbs. K, Ca, S, Mg, Fe and Al contents were determined as main minerals in both oven and sun dried basil. **Abdel-Galil and El-Nakib (2008)** investigated the effect of two different natural convection solar drying systems on the quality of two species of peppermint (mentha pepperita and mentha vridis). They reported that oven drying method gave the lowest essential oil and chlorophylls A and B contents as compared with the two solar drying methods. Also, the essential oil content and chlorophylls A and B contents were slightly higher for the direct dryer as compared with that of the indirect dryer. **Banout *et al.* (2010)** studied two solar drying methods (direct cabinet solar dryer and indirect cabinet solar dryer) on the chemical composition of aerial parts of sacha culantro (*Eryngium foetidum).* The authors concluded that when comparing both solar drying methods, the indirect method was found as more suitable for drying *E. foetidum* since the dried product   resembled the fresh herb more closely in its chemical composition and had better appearance. Many other authors found variations in the chemical composition of essential oil of different medicinal plants according to the drying air temperature (**Khangholil and Rezaeinodehi, 2008; Baydar and Erbas, 2009; Sellami *et al*., 2011**).

The specific objectives of this study are to:

1. Design and construct a solar drying unit able to dry aromatic and medicinal plants and evaluate its thermal performance.
2. Investigate the factors affecting the drying process of basil leaves.
3. Determine most important chemical characteristics of dried basil leaves.

MATERIALS AND METHODS

A. The Solar dryer set-up:

Two similar solar drying units were developed and constructed for drying sweet basil leaves in Fayoum Faculty of Agriculture, Fayoum University, Egypt on August, 2014 by using heated air. The latitude and longitude angles for the specific location are 29.18^{o} N and 30.3^{o}, respectively. Each drying unit consists of a solar collector attached with drying chamber. The only difference between the two drying units was in the air suction fan of each solar collector, whereas, the drying chamber is similar for both units. Fig. (1) shows a photograph of the experimental set up. A

schematic representation for the solar drying unit of the experimental set-up is shown at (Fig.2), and the following are details of the components:

1. Flat-plate solar collector: A single flat-plate solar collector with airflow over the absorber was made of rectangular wooden box. It has a surface area of 2.0 m^2 (2.0 m long, 1.0 m wide and 0.15 m thickness). The solar collector was painted from inside and outside surfaces using matt black paint. Galvanized flat metal plate painted matt black which having absorpitivity and emissivity of 0.95 and 0.87 respectively, was used as an absorber plate to absorb the maximum amount of solar energy. Transparent cover of glass sheet (2.7 mm thickness) is placed 7cm on the upper side of absorber plate to reduce thermal losses. A fiber glass wool (24 kg. m^{-3}) with thickness of 0.025 m and a thermal conductivity of 0.045 W.m^{-1}.$^{\circ}$C^{-1} was used to insulate the sides and bottom of the solar collector. A suction fan with control valve at its outlet (150 mm diameter, model No.OC-15R, 220 Volt, 50 Hertz, Ocarina made) was attached in the front entrance of the solar collector to introduce the ambient air (T_a) to it for heating and, then, passes through the drying chamber. The suction fan was lifted up from the earth's surface, to prevent the air entering the solar collector from pollution, and to avoid the air from mixing with dust. Three openings were made at the other end of the solar collector to introduce the heated air to the drying chamber. The solar collector was orientated to face south direction and tilted with an optimum tilt angle.

2. Drying chamber: The drying chamber was a rectangular box (1.0 m length, 1.0 m width and 0.8 m depth) constructed of wooden. In the middle of the drying chamber, wooden supports were fixed at two parallel sides of it for placing the drying tray. The drying tray was made of an iron frame with 0.2 cm mesh stainless steel wire screen to permit drying air passing throughout it. The drying tray was divided into three sections: the first section of the 2-cm, the second section of the 4-cm and the third section of the 6-cm sweet basil leaves thickness layers. The drying tray was inserted into (or removed from) the drying chamber through a hinged door, which was tightly sealed during the drying process. The inlet and outlet ducts (0.5 × 0.5 m) with 0.15 m depth were attached to the drying chamber to allow uniform air distribution inside it and delivers the exhaust air to the atmosphere. Two Orifice plates with 2.0 cm openings were used to measure the airflow rate. The exhaust air leaves the drying

through the chimney, which was protected by a cover to prevent the ambient air from entering the drying chamber when the drying process was off. The drying chamber was painted from outside surfaces using matt black paint to minimize the heat losses to the ambient atmosphere, especially during the drying process. The drying chamber was mounted on a wooden stand which was elevated by 1.5 m from the ground.
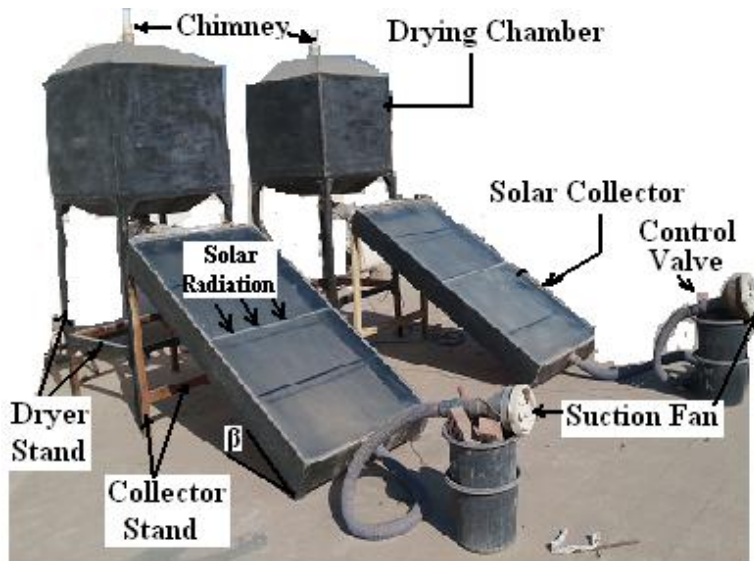

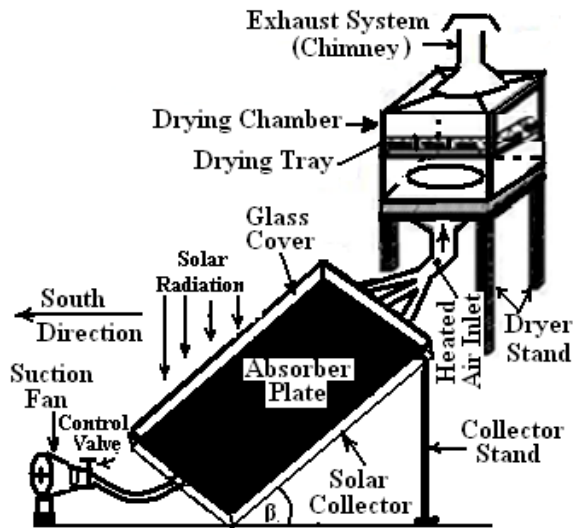Fig. (1): A Photograph Showing the Experimental Set Up.

Fig. (2): Schematic Representatiomn of the Experim,ental Set Up

B. Some physical properties of sweet basil:

Sweet basil is a common name for the culinary herb *"Ocimum basilicum"* of the family ***Lamiaceae***. Sweet basil leaves may taste somewhat like anise, with a strong, pungent, often sweet smell. There are many varieties of *"Ocimum basilicum"*, as well as several related species or species hybrids also called basil. The type used in Italian food is typically called sweet basil, as opposed to Thai basil (***O. basilicum* var. *thyrsiflora***), lemon basil (***O. X citriodorum***) and holy basil (***Ocimum tenuiflorum***), which are used in Asia. While most common varieties of basil are treated as annuals, some are perennial in warm, tropical climates, including holy basil and a cultivar known as 'African Blue'. Physical properties of sweet basil which used in this study were determined, and presented in Table (1).

C. Meteorological measurements and Instrumentation: Solar radiation intensity (I, $W.m^{-2}$), air temperature (T, ^{o}C), and relative humidity (Rh, %) were measured daily from sunrise to sunset for the period of study.

1. Solar intensity measurement: The solar radiations flux incident on a horizontal and tilted surfaces were measured using a data acquisition system (TENMARS – Solar Power Meter – TM-206), with a measurement of 0.0 to 1999 $W.m^{-2}$ and an accuracy of 0.1 $W. m^{-2}$ over a spectral range of 300 to 1100 nm. Data were collected daily by a data logger at each 10 min. and averaged over a time of 1 hr. interval.

Table (1): Physical properties of basil leaves.

Properties	Measured value		Average
	maximum	minimum	
Plant color	Light green	Light green	Light green
Leaf type	silky leaves	silky leaves	silky leaves
Plant sensitivity to weather conditions	Very sensitive to cold	Very sensitive to cold	Very sensitive to cold
Plant height, cm	130	30	80
Leaf length, cm	11	3	7
Leaf breadth, cm	6	1	3.5
Basil leaf thickness, mm	0.41	0.33	0.37
Initial moisture content of basil leaves (%, w.b)	86.36	84.68	85.52

2. Temperature and relative humidity measurements: Temperature and relative humidity inside and outside the solar drying unit were measured using a TENMARS-TM305-Temperature/Rh Data-logger (TENMARS ELECTRONICS CO., NEIHU, TAIWAN) and the specifications of this device are shown in Table (2). The air temperature and relative humidity were recorded daily for the period of study. Data were recorded at each 10 min. by the data-logger and averaged over a time of 1 hr. interval. The temperature and relative humidity sensors were placed in multi-plate radiation shields above the ground by one meter to protect them from error-producing by solar radiation and precipitation.

Table (2): Specifications of temperature and humidity Data-logger.

Item	Specifications	
	Temperature	Humidity
Measurement Range	-40 °C to 85 °C	1 % to 99 %
Accuracy	±0.6°C from-20°C to 50°C ±1.0°C for all other ranges	±3.0%RH(20%~80%) ±5.0%RH(<20%,>80%)
Resolution	0.1 °C	0.1 %
Type	-	Capacitor

3. Airflow rate measurement: The airflow rate ($m^3.s^{-1}$) was measured using an orifice plates. The orifice plates were designed according to the International Standards Organization Standard No. ISO 5167-1980(E).

4. Moisture content measurement: An electric balance and electric oven were used for weighing and drying samples to determine the moisture content of both fresh and dried sweet basil leaves before and during the drying process. The capacity of the electric balance was 1 kg with accuracy of ± 0.01g. The samples were taken every two hour interval and dried on the electric oven at 105 ^{o}C for 24 hrs. The moisture content of sweet basil leaves was calculated on both wet and dry bases.

D. Chemical analysis: The chemical analysis was performed on both fresh and dried sweet basil leaves samples for the determination of the oil content (%) and chlorophyll content (mg/g). The essential oil was determined according to the method described in the British Pharmacopoeia (1963). Total chlorophyll contents were determined according to the method mentioned by **Brougham (1960)**.

E. Experimental Procedure: At the beginning of each experimental run, sweet basil leaves (*Ocimum sanctum*) were separated from basil plants and washed in tap water. Excess surface water from washed basil leaves was removed using blotting paper with slight pressing. Three different weights of each representative samples (clean leaves) were used to determine the average initial moisture content of basil leaves. The obtained results showed that the average initial moisture content of basil leaves was 85.52% w.b (590.73% d.b), which were used for drying purpose on the same day. During the basil leaves drying process, both the drying units were operated simultaneously whereas during night (when the drying units were shut-off), both of the air inlet and outlet of each dryer unit were handily closed to maintained the drying chamber temperature at the desired temperature. For each drying run, the masses of labeled basil leaves samples were measured initially and every one hour intervals daily for determining the moisture content of basil leaves. The total and actual drying times, moisture removed from basil leaves were computed for each experimental run. The drying effectiveness (h/g moisture) is defined as the time required for removing 1 g moisture from the basil leaves during the experimental run. It was calculated by dividing the actual drying time by the amount of moisture removed from the basil leaves during the drying process. At the beginning of each drying run, the chemical analyses (oil content (%) and chlorophyll content (mg/100g)) for fresh sweet basil leaves were determined. These chemical analyses for solar-dried basil leaves were determined at two airflow rates (0.015 m^3/s and 0.025) and three basil leaves depths (2, 4 and 6 cm), while for sun-dried basil leaves (natural drying), the chemical analyses were determined at the same previous depths. The chlorophyll content (mg/g) was determined by using a spectronic 20D spectrophotometer (**Brougham, 1960**). The oil percentage (%) was calculated (**according to Guenther, 1975**) using the following formula:

$$X_o = \rho_o \times V_o \times 100 / W_L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: X_o is the percentage of the volatile oil, (%); ρ_o is the density of the volatile oil, (g.cm^{-3}); V_o is the volume of the volatile oil, (cm^3) and W_L is the weight of sample, (g).

F. Thermal Performance of Solar Collector:

The thermal performance of the solar collector was estimated using the following equations:

1. Hourly average solar energy available on the collector surface (q_{av}): The hourly average total solar radiation available on the specific tilted surface of the solar collector was calculated using the following formula:

$$q_{av} = I_T \times A_C, \quad (Watt) \quad \dots\dots\dots\dots\dots\dots\dots\dots\text{(2)}$$

Where: I_T is the solar radiation flux on the tilted solar collector, $(W.m^{-2})$.

A_C is the surface area of the solar collector, (m^2).

2. Useful heat energy gain (Q_{us}): The useful heat energy gain is calculated as follows:

$$Q_{us} = m \, Cp \, (T_{ao} - T_{ai}), \quad (Watt)\dots\dots\dots\dots\dots\dots\text{(3)}$$

Where: m is the air mass flow rate, $(kg. \, s^{-1})$; Cp is the specific heat of air, $(J. \, kg^{-1} \,.^{o}C^{-1})$; T_{ao} and T_{ai} are the outlet and inlet air temperatures of the solar collector, (^{o}C).

3. The thermal efficiency of the solar collector (η_{th}): The thermal efficiency of the solar collector is calculated as follows:

$$\eta_{th} = Q_{us} / q_{av} = [m \, Cp \, (T_{ao} - T_{ai})] / (I_T \times A_C), \quad (\%) \dots\text{(4)}$$

G. Calculations of the solar radiations:

The estimated data was calculated by Excel–2003 Software. These calculations include:

- A technique of estimating the hourly average total solar radiation flux available on and gained on a south-facing solar collector using the meteorological and geographical parameters for Fayoum City (latitude and longitude angles are 29.18^{o} N, 30.30^{o}, respectively), Fayoum, Egypt on August.

- The procedure for obtaining the thermal efficiency of a solar collector for a flat-plate flow-over-absorber.

RESULTS AND DISCUSSIONS

Estimation of solar radiation and influences of some factors on the performance of the solar collector can be discussed as follows:

A. Solar radiation intensity and collector efficiency:

1. Hourly average incident solar radiation: The measured hourly average solar radiations incident on the horizontal plane and both of tilted

surfaces, oriented at optimum angle (15.7^o) and latitude angle (30°) for the month of August (2014) were hourly measured and the results were illustrated in Fig. (3). The results showed that, the hourly average solar radiations incident on the tilted surfaces of the solar collectors oriented at optimum and latitude angles almost clarified the same trend of that incident on the horizontal surface. The maximum values of hourly average solar radiations incident on the horizontal plane and tilted surface, oriented at optimum angle (15.7^o) occurred at 12:00 noon, while the maximum values of the tilted surface oriented at latitude angle occurred at 2.00 pm. The daily average total solar radiations flux incidents on the tilted surfaces oriented at optimum angle (15.7^o) and latitude angle (30°) were 29.30 MJ.m^{-2}.day^{-1} and 24.62 MJ.m^{-2}.day^{-1}, respectively. Meanwhile, the daily average total solar radiation incident on the horizontal plane was 24.30 MJ.m^{-2}.day^{-1}. Consequently, the tilted surface of the solar collector inclined with an optimum tilt angle (15.7^o) for the month of August increased the solar energy by 20.58%, because the optimum angle causes the beam radiation to be perpendicular on the collector surface during most of the day-time. On the other hand, the hourly average solar radiation incident on the horizontal plane was approximately equal to that incident on tilted surface oriented at latitude angle (30°). It was higher than that incident on tilted surface oriented at latitude angle (30°) before noon. Conversely, the hourly average solar radiation incident on tilted surface oriented at latitude angle (30°) was higher than that incident on the horizontal plane after noon until sunset.

2. Hourly average useful energy gain and thermal efficiency of the solar collectors: Because the higher values of the daily average solar radiations flux incident on the tilted surfaces oriented at the optimum angle (15.7^o), which causes the beam radiation to be perpendicular on the collector surface during most of the day-time. Therefore, it was decided to calculate the average hourly useful energy gained and the thermal efficiency of both solar collectors tilted at the optimum tilt angle (15.7^o) for the month of August at two different airflow rates (0.015 and 0.025 m^3.s^{-1}) for Fayoum, Egypt (2014), and the results are shown in Table (3).
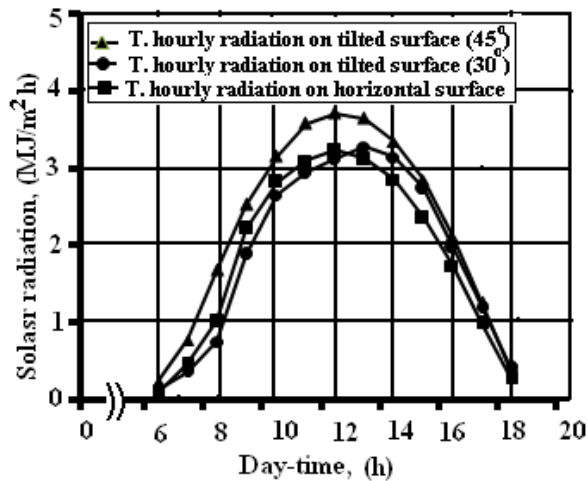
Fig. (3): Measured values of hourly average solar radiation
incident on horizontal and tilted surfaces at latitude
and optimum angles, for Fayoum, Egypt, in August.

The estimated values of the hourly average solar radiation incident on horizontal and tilted surfaces were measured, and used to calculate the solar energy gained and thermal efficiencies of the collectors. It̓s clear that, the hourly average overall thermal efficiency of the solar collector almost clarified the same trend of the useful energy gained, where the maximum value occurred at 12:00 noon. The results revealed that the hourly average overall thermal efficiency for the solar collector tilted at the optimum angle with the higher airflow rate was 43.11%, which is relatively higher than that (40.88%) with the lower airflow rate. Consequently, the solar collector with the higher airflow rate increased the hourly average overall thermal efficiency of the solar collector by 5.46 % as compared with that of the lower airflow rate. Thus, for the purpose of solar drying, the maximum solar energy collection is desired for a given month to maximize the amount of solar energy gained by the solar drying unit and, consequently increasing its efficiency.

B. Inlet and outlet air temperatures of the solar collectors: The hourly average ambient temperature (T_a) for Fayoum, Egypt and the outlet air temperature of the solar collector (T_o) tilted at the optimum tilt angle (15.7°) was measured at two different airflow rates (0.015 $m^3.sec^{-1}$ and 0.025 $m^3.sec.^{-1}$) during the experimental period (August, 2014) and the results are graphically illustrated in Fig. (4).

Table (3): Estimated values of hourly average solar radiation, gained energy and thermal efficiency of two solar collectors oriented at the optimum tilt angle (15.7°) for Fayoum, Egypt on August, 2014.

Day-time, (h)	Solar radiation, $(MJ.m^{-2}.h^{-1})$		Gained energy and efficiency of a solar collectors			
	I^*	I_T^{**}	Gained energy,(Q_{us})		Thermal efficiency, ŋ (%)	
			(0.015)	(0.025)	(0.015)	(0.025)
6	0.10	0.24	0.03	0.04	12.50	16.66
7	0.46	0.78	0.18	0.21	23.08	26.92
8	1.02	1.68	0.41	0.44	24.40	26.19
9	2.22	2.53	0.78	0.82	30.83	32.41
10	2.82	3.16	1.32	1.38	41.77	43.67
11	3.10	3.58	1.64	1.72	45.81	48.05
12	3.23	3.72	1.76	1.88	47.31	50.54
13	3.12	3.65	1.69	1.72	46.30	47.12
14	2.86	3.35	1.48	1.53	44.18	45.67
15	2.36	2.86	1.22	1.27	42.66	44.41
16	1.74	2.12	0.86	0.92	40.57	43.40
17	0.99	1.26	0.47	0.49	37.30	38.89
18	0.28	0.36	0.12	0.13	33.33	36.11
Sum.	24.3	29.30	11.96	12.55	—	—
Average	1.87	2.25	0.92	0.97	40.88	43.11

* I = Hourly average radiation incident on the horizontal surface, $(MJ.m^{-2}.h^{-1})$

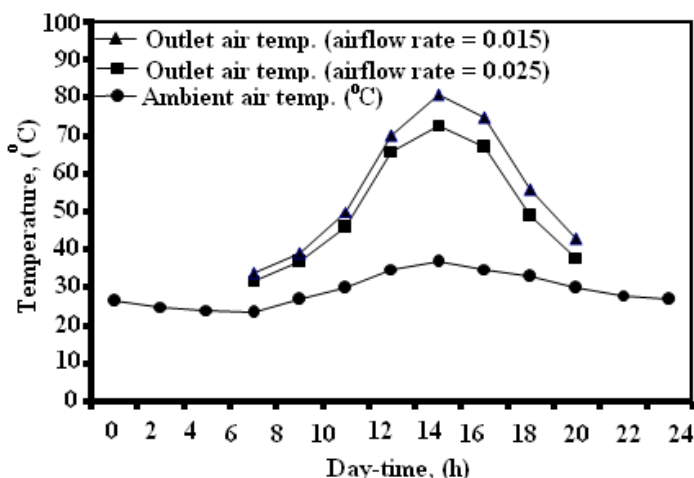** I_T = Hourly average radiation incident on tilted surface, $(MJ.m^{-2}.h^{-1})$

Fig. (4): Measured hourly average ambient and outlet temperatures of a solar collectors oriented at optimum tilt angle operated with two different airflow rates for Fayoum, Egypt, in August, 2014.

The results showed that, the outlet air temperature of the solar collector at two airflow rates were higher in most of the day-time (from 6:0 am to 8:0 pm) as compared with the corresponding values of the ambient temperature and almost take the same trend. The maximum values of the outlet temperatures for the solar collector with airflow rates of 0.025 and 0.015 $m^3.sec.^{-1}$ were recorded to be 73.0 ^{o}C and 81.0 ^{o}C, respectively, (at 2:0 0 pm), whereas, the ambient air temperature reached to the maximum value of 37.0 ^{o}C (at 2:00 pm). The outlet air temperatures of the solar collector operated with airflow 0.015 $m^3.sec^{-1}$ were higher as compared with the corresponding values of the outlet temperatures with airflow rate of 0.025 $m^3.sec.^{-1}$. At August (2014), the diurnally temperature cycle ranged from 23.5 ^{o}C to 37.0 ^{o}C during the time of the day, while the two airflow rates provided two drying air temperature cycles (day-time) ranged from 32.0 ^{o}C to 73.0 ^{o}C and from 34.0 to 81.0 ^{o}C for the airflow rates of 0.025 $m^3.sec.^{-1}$ and 0.015 $m^3.sec.^{-1}$, respectively. The results indicated that, the outlet temperature of the collector (drying air temperature) increased as the air flow rate decreased.

Two statistical equations were resulted from Excel-2003, which described the relationship between the outlet air temperatures from the solar collectors (at two airflow rates) and the hourly solar radiation incident on the horizontal plane ($MJ.m^{-2}.h^{-1}$). The following formulas are resulted:

$$T_{out\ (0.025)} = 4.423\ (I)^2 - 5.245\ (I) + 36.15\ ……..\ (5)$$
$$T_{out\ (0.015)} = 4.283\ (I)^2 - 5.335\ (I) + 34.27\ ...……\ (6)$$

Where: $T_{out\ (0.025)}$ and $T_{out\ (0.015)}$ are the outlet air temperatures from the solar collectors at air flow rates of 0.025 and 0.015 $m^3.sec^{-1}$, respectively, and I is the hourly solar radiation incident on the horizontal plane (From 1.0 to 4.0 $MJ.m^{-2}.h^{-1}$).

C. Drying Rate of basil leaves: Generally, in the drying process, the rate of moisture loss is very important, since it affects the changes in the product properties. Therefore, effect of three basils leaves thicknesses (2, 4 and 6 cm) and two airflow rates (0.015 and 0.025 $m^3.sec^{-1}$) were investigated, in order to evaluate their effects on the drying-rate of basil leaves.
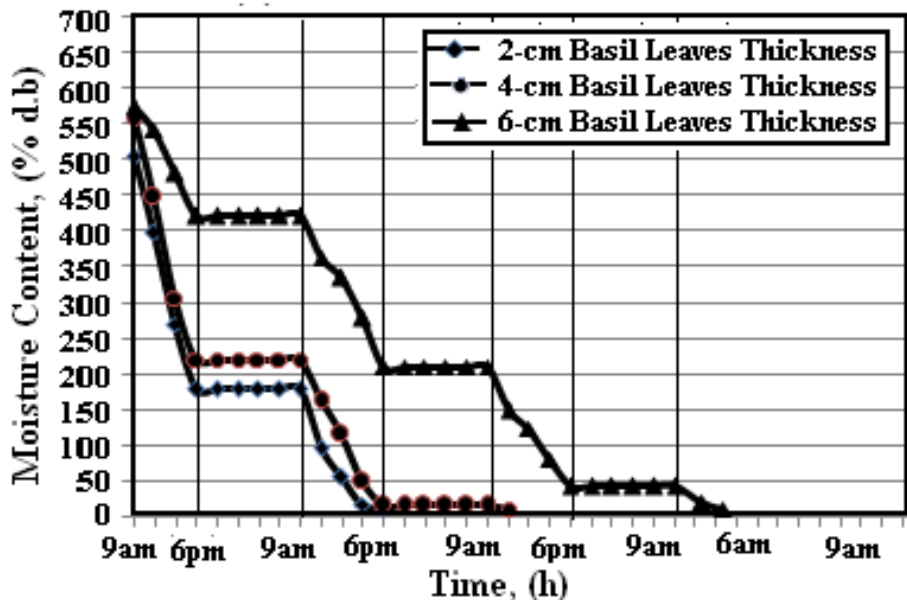
1. Effect of basil leaves thickness on the drying rate: Fig. (5) shows the moisture content of basil leaves determined at two different airflow rates

(0.015 and 0.025 m^3.sec.$^{-1}$) for three different basil leaves thicknesses (2, 4 and 6 cm). It is clear that, the 2-cm thick basil leaves layer dried fastest at both airflow rates, followed by the 4-cm and the 6-cm thick layers. The results indicated that, the finally average moisture contents (equilibrium) of basil leaves at all basil leaves thicknesses were found to be 11.52 % (d.b.) and 14.58 % (d.b.) at airflow rates of 0.015 and 0.025 m^3.sec.$^{-1}$, respectively. This means that increasing the drying air temperature was sufficient to decrease the relative humidity and, thus, to increase the capacity of air to absorb moisture from the basil leaves, especially at the end stage of the drying process (when the moisture content of the basil leaves was low). At airflow rate of 0.015 m^3.sec^{-1} (drying air temperature cycle of 34.0 - 81.0 ^{o}C), the moisture content of basil leaves reached its equilibrium after a total drying time of approximately 48, 69 and 121 h for the 2, 4 and 6 cm basil leaves thicknesses, respectively (Fig. 5-a), whereas at airflow rate of 0.025 m^3.sec^{-1} (drying air temperature cycle of 32.0 - 73.0 ^{o}C), the moisture content reached its equilibrium after a total drying time of approximately 45, 63 and 94 h for the 2, 4 and 6 cm for the same basil leaves thicknesses, respectively (Fig. 5-b).

2. Effect of airflow rate on the drying rate: Fig. (6) shows the moisture content of basil leaves determined at three basil leaves thick-layers (2, 4 and 6 cm) for two different airflow rates (0.015 and 0.025 m^3.sec.$^{-1}$). At the 2 cm basil leaves thick-layer (Fig. 6-a), the moisture content reached its equilibrium after total drying time of approximately 48 and 45 h at the airflow rates of 0.015 and 0.025 m^3.sec.$^{-1}$, respectively. At the 4 cm basil leaves thick-layer (Fig. 6-b), the moisture content reached its equilibrium after total drying time of approximately 69 and 673 h at the airflow rates of 0.015 m^3.sec.$^{-1}$ and 0.025 m^3.sec.$^{-1}$ respectively, whereas at 6 cm basil leaves thick-layers (Fig. 6-c), the moisture content reached its equilibrium after total drying time of approximately 121 and 94 h at airflow rate of 0.015 m^3.sec.$^{-1}$ and 0.025 m^3.sec.$^{-1}$ respectively. It is clear that, the lower moisture content was obtained at the higher airflow rate (0.025 m^3/s) as compared with the corresponding values, which obtained at the lower airflow rate (0.015 m^3/s) at all basil leaves thicknesses. This means that, increasing the airflow rate was sufficient to increase the capacity of air to absorb more moisture from the basil leaves.
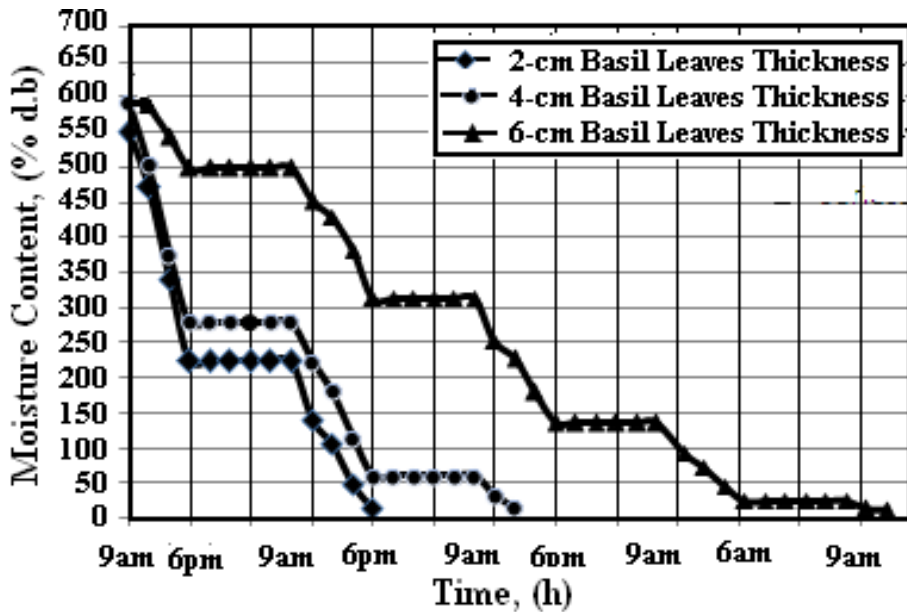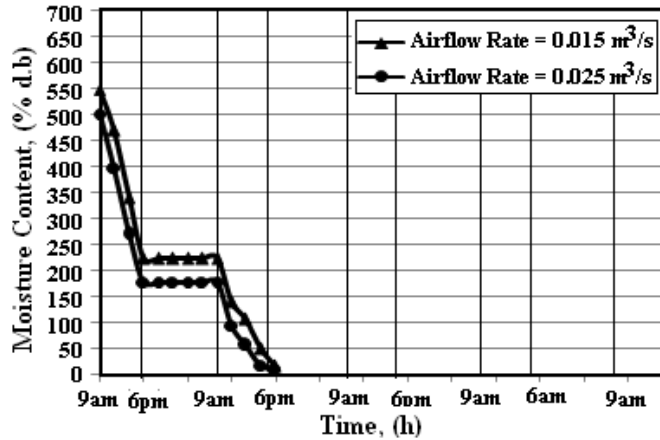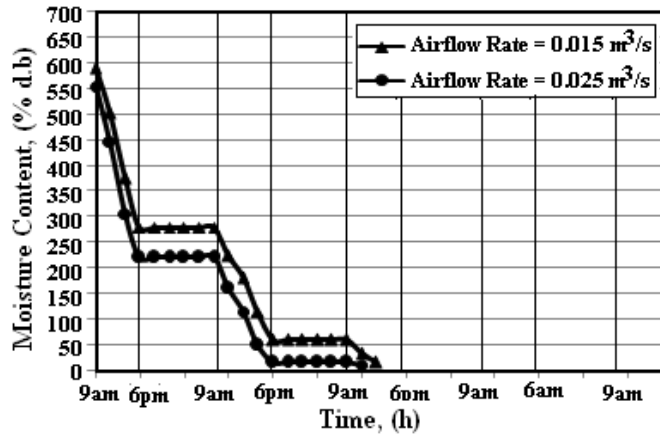
(a) Airflow Rate = 0.015 m³/s
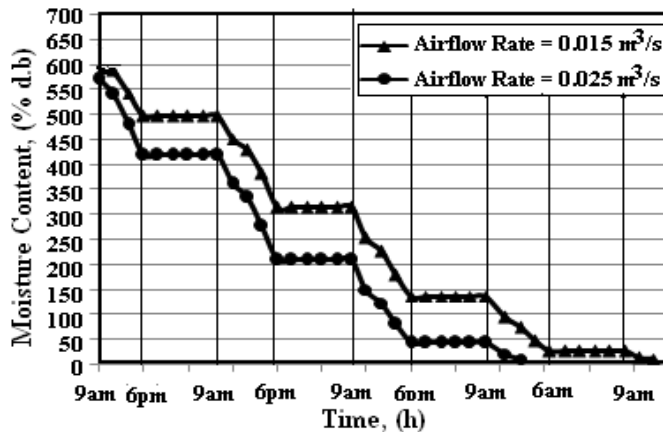

(b) Airflow Rate = 0.025 m³/s

Fig. (5): Effect of basil leaves thickness on the moisture
content of basil leaves at different airflow rates

(a) Basil Leaves Thickness = 2 cm

(b) Basil Leaves Thickness = 4 cm

(c) Basil Leaves Thickness = 6 cm

Fig. (6): Effect of airflow rate on the moisture content of basil leaves at different basil leaves thicknesses

3. Drying effectiveness: The total and actual drying times, and the moisture removed from basil leaves during the drying processes were calculated to obtain the drying effectiveness (h. g^{-1} moisture) and the results are shown in Table (4). These calculations were made in order to compare the trends of the basil leaves drying effectiveness at various basil leaves thicknesses and airflow rates. It is clear that, the time required for driving off 1 g of moisture from the basil leaves decreased as both the airflow rate and basil leaves thickness increased. Thus, the least time required for drying basil leaves was for the 6-cm thickness, followed by the 4-cm and 2-cm basil leaves thicknesses at both airflow rates. On the other hand, the time required to drive off 1g of moisture from the basil leaves for the 2, 4 and 6 cm-thick layers with the airflow rate of 0.015 $m^3.s^{-1}$ were 0.341, 0.241 and 0.223 h. g^{-1} moisture removed respectively, which was 3.96%, 7.1% and 3.72% higher than the corresponding values (0.328, 0.225 and .215 h. g^{-1} moisture removed) with the lower airflow rate (0.025 $m^3 .s.^{-1}$), respectively.

Table (4): Drying time and drying effectiveness of basil leaves at various airflow rates and basil leaves thicknesses.

Airflow rate (m^3/s)	Basil leaves thickness (cm)	Drying time (h)		Basil leaves weight (g)		Moisture removed (g)	Drying Effectiveness (h/g moisture)
		Total	Actual	Initial	Fianal		
0.015*	2	034	20	071.35	12.76	058.59	0.341
	4	069	24	128.13	28.46	099.67	0.241
	6	121	42	222.49	34.14	188.35	0.223
0.025**	2	32	18	062.96	08.12	054.84	0.328
	4	63	21	107.43	13.98	093.45	0.225
	6	94	34	176.30	18.24	158.06	0.215

* Drying air temperature cycle = 34 - 81°C
** Drying air temperature cycle = 32 - 73.°C

The basil leaves thickness is one of the most important parameter affecting the basil leaves drying rate (g moisture removed /h). Fig. (7) shows the basil leaves drying rate at different basil leaves thicknesses with two airflow rates. It is clear that, the basil leaves drying rate increases as the basil leaves thickness increases and vice versa. Two equations were developed by the Excel-2003 soft-ware, and the following formulas are resulted:

$$D_{r\,(0.015)} = 2.511\ e^{0.102\ (D)} \quad\dots\dots\dots\dots\ (7)$$

$$D_{r\,(0.025)} = 2.638\ e^{0.103\ (D)} \quad\dots\dots\dots\dots\ (8)$$

Where: $D_{r\,(0.015)}$ and $D_{r\,(0.025)}$ are the drying rates (g $_{moisture}$ removed . hr^{-1}) with airflow rates of 0.015 and 0.025 m^3 .sec $^{-1}$, and D is the basil leaves thickness (cm).
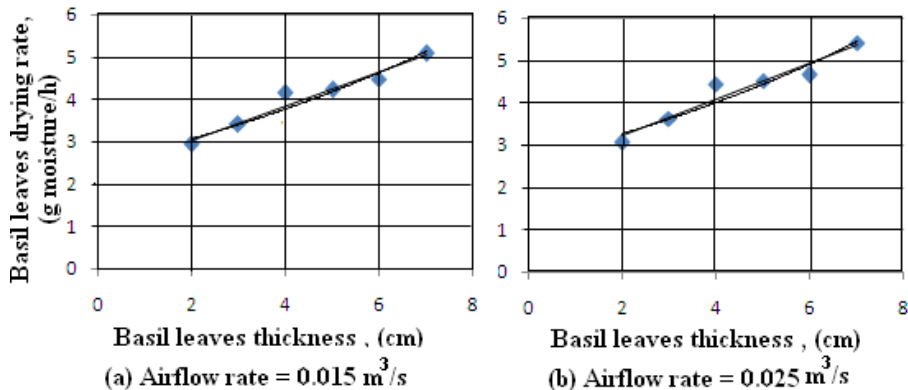

Fig. (7): Effect of basil leaves bthickness on the basil leaves drying rare with two different airflow rates.

D. Effect of drying methods on quality of basil leaves: The solar drying method was found as more suitable for drying basil leaves, since the final dried product resembled the fresh basil leaves more closely in its chemical composition and had better appearance. The final dried product by the solar dryer (heated-air method) is better, clean and having a good quality as compared to that dried directly at the sun rays because it provides isolated atmosphere and suitable drying temperatures which minimize the contamination of the dried product. The solar dryer kept total chlorophyll contents of basil leaves higher than that dried directly at the sun while, on contrast, the essential oil contents of basil leaves were slightly higher for sun-dried as compared with that dried at the solar dryer (heated-air method).

F. Chemical analyses of sweet basil leaves: The chemical analyses for both fresh and dried basil leaves were determined and the results are listed in Table (5). The chemical analyses showed that the percentages of essential oil content and total chlorophyll contents in fresh-basil leaves were higher than that in both solar-dried and sun-dried basil leaves for the three different depths used. It's clear that, the percentages of essential oil

content in solar-dried basil leaves at all depths increased when the air flow rate is increased, while on contrast, the total chlorophyll content in solar-dried basil leaves increased when the air flow rate is decreased. This due to the fact that increasing the airflow rate decreases the outlet temperature of the solar collector (inlet air to the drying chamber). On the other hand, the percentages of essential oil content for sun-dried basil leaves were slightly higher than that of solar-dried basil leaves at all depths, because the drying air temperatures for direct sun-drying were lower (ambient temperature). For the solar-dried basil leaves, the heated air drying method with air flow rate of 0.015 $m^3.s^{-1}$ and 2-cm basil leaves depth gave the highest essential oil contents, while the heated air drying method with air flow rate of 0.025 $m^3.s^{-1}$ and 4-cm depth gave the highest values of total chlorophyll contents.

Table (5): Chemical analysis of sweet basil leaves as affected by the drying method.

Type of basil leaves	Air-flow rate, (m^3/s)	Basil leaves depth, (cm)	Oil content, (%)	Chlorophyll, (mg/100g)
Solar-dried basil leaves	0.015^*	2	1.021	72.512
		4	1.072	89.020
		6	1.276	65.977
	0.025^{**}	2	1.314	57.222
		4	1.289	63.739
		6	1.302	48.462
Sun-dried basil leaves	Natural drying	2	1.436	49.332
		4	1.302	70.611
		6	1.518	54.049
Fresh basil leaves	—	—	2.159	119.540

Average of 3 replicates.
* At drying air temperature cycle = 32.0 to 81.0 °C.
**At drying air temperature cycle = 30.0 to 76.0 °C

CONCLUSION

The tilted surface of the solar collector inclined at the optimum tilt angle increased the solar radiation incident on the horizontal surface by 20.58%. The higher airflow rate (0.025 $m^3.s^{-1}$) increased the hourly average overall thermal efficiency of the solar collector by 5.46 % as compared with the

lower airflow rate (0.015 m^3.s^{-1}). So that, the best results of basil leaves drying appeared with the higher air flow rate, this due to the high velocity of dry air with airflow rate of 0.025 m^3.s^{-1} which, passed through the basil leaves compared with the low velocity of the lower airflow rate (0.015 m^3.s^{-1}). The final moisture content of dried basil leaves ranged from (11.52% to 14.58% d.b) depending on the drying temperature cycle. Very small changes were observed in the colour and shape of heated-air dried basil leaves as compared to that dried at direct sun rays. The essential oil contents of dried basil leaves were slightly higher for the drying unit with the higher airflow rate as compared with the corresponding values obtained from the drying unit with the lower airflow at all basil leaves thicknesses. While on Contrast, total chlorophylls contents were slightly higher for the drying unit with the lower airflow rate as compared with the corresponding values obtained from the drying unit with the higher airflow at all basil leaves thicknesses. Under the conditions of this study, the optimum depth to dry basil leaves by using heated air is 4 cm.

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الملخص العربي

تصميم وتشييد وتقييم أداء وحدة تجفيف شمسي لأوراق الريحان

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أجرى هذا البحث بهدف تصميم وتشسييد وتقييم أداء وحدة للتجفيف الشمسى بالهواء المسخن، حيث تم تصميم هذه الوحدة وتنفيذها وتقييم أدائها فى كلية الزراعة – جامعة الفيوم ـ محافظة الفيوم، وقد أستخدمت هذه الوحدة لتجفيف أوراق الريحان الذى يعتبر من النباتات الطبية والعطرية الرئيسية والتصديرية فى محافظة الفيوم. ولتنفيذ هذه التجارب، فقد تم عمل وحدتين متماثلتين للتجفيف الشمسى، حيث تم تثبيتهما على السطح العلوى لمبنى قسم الأراضى والمياه بكلية الزراعة بالفيوم. وتتكون كل وحدة منهما من جزئين رئيسيين هما المجمع الشمسى الذى يقوم بتسخين الهواء الجوى ودفعة بفعل الحمل الجبرى والثانى هو غرفة التجفيف والتى تعتبر بمثابة وحدة التجفيف الرئيسية، حيث نم تزويدها بصوانى تجفيف مصنوعة من هيكل خشبى (مفرغ من الجانبين) ومزود بشباك سلكية من الصلب لكى تسمح للهواء الساخن بالعبور علي المواد الموضوعة فى هذه الصوانى والمراد تجفيفها وبالتالى زيادة معدل التجفيف. وقد اجريت تجارب تجفيف أوراق الريحان لملاحظة وتحديد مدى إستجابة نظام التجفيف الشمسى المناسب لمستويين من معدل سريان الهواء (٠.٠١٥ م³/ث ، ٠.٠٢٥ م³ /ث) وثلاثة أسماك مختلفة لأوراق الريحان (٢ ، ٤ ، ٦ سم) عند دورة من درجات الحرارة اليومية خلال ساعات النهار (من ٢٦.٨ م° إلى٤١.٢ م° خلال شهر أغسطس لعام ٢٠١٤).

وقد أوضحت نتائج الدراسة مايلى:

١. كان المتوسط اليومى لكمية الا شعة الشمسية الكلية الساقطة على سطح المجمع الشمسى المائل (بزاوية ميل مثلى ١٥.٧°) ٢٩.٣٠ ميجاجول/ م² . اليوم، حيث كان فى المتوسط أعلا من تلك الساقطة على السطح الأفقى (٢٤.٣٠ ميجاجول/ م² . اليوم) بنسبة ٢٤.٨٥ %.

٢. تأثرت درجة حرارة الهواء الساخن الخارج من المجمع الشمسى بمعدل سريان الهواء، حيث كان المتوسط اليومى لدورتى درجات حرارة هواء التجفيف أثناء النهار ٣٤.٠ – ٨١.٠°م ، ٣٢.٠ – ٧٣.٠ °م عند معدلى سريان هواء ٠.٠١٥ م³/ث ، ٠.٠٢٥ م³ /ث على الترتيب

٣. كان المتوسط الكلى للكفاءة الحرارية فى اليوم للمجمع الشمسى ٤٠.٨٨% ، ٤٣.١١% عند معدلى سريان هواء ٠.٠١٥ م³/ث ، ٠.٠٢٥ م³ /ث على الترتيب، حيث أدى زيادة معدل سريان الهواء إلى زيادة كفاءة المجمع الشمسى بنسبة ٥.٤٦%.

٤. تأثر المحتوى الرطوبى لأوراق الريحان كثيراً بسمك طبقة أوراق الريحان ومعدل سريان الهواء عند دورتين من درجات حرارة هواء التجفيف أثناء النهار (٣٤.٠ – ٨١.٠°م ، ٣٢.٠ – ٧٣.٠°م). وعموماً فإن زيادة معدل سريان الهواء أو زيادة سمك أوراق الريحان أو كليهما معاً أدى إلى تقليل الوقت المطلوب للتجفيف.

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٥. تراوح المحتوى الرطوبى النهائى لأوراق الريحان المجففة من ١١.٥٢% إلى ١٤.٥٨% على أساس الوزن الجاف معتمداً على دورة درجات حرارة هواء التجفيف المستخدمة.

٦. كانت أوراق الريحان المجففة بالهواء الساخن فى المجفف الشمسى ذو جودة عالية، حيث أظهرت تغيراً صغيراً جداً من حيث الشكل واللون مقارنة بأوراق الريحان المجففة طبيعياً من خلال التعريض لأشعة الشمس المباشرة.

٧. أدى إستخدام التجفيف الشمسى الغير مباشر بالهواء المسخن إلى الحفاظ على محتوى الزيوت الطيارة عند أعلى قيمة ممكنة، حيث كانت نسبة الزيوت الطيارة فى أوراق الريحان المجففة بإستخدام معدل سريان هواء كبير (٠.٠٢٥ م٣/ث) أعلى نسبيا من مثيلتها فى الأوراق المجففة بإستخدام معدل سريان هواء صغير(٠.٠١٥ م٣/ث) عند جميع أسماك أوراق الريحان.

٨. أعطى المجفف الشمسى ذو معدل سريان الهواء الصغير (٠.٠١٥ م٣/ث) قيماً أعلى لمحتوى للكلوروفيل الكلى مقارنة بالمجفف الشمسى ذو معدل سريان الهواء الكبير (٠.٠٢٥ م٣/ث) عند جميع أسماك أوراق الريحان.

٩. أستنبطت معادلتين احصائيتين للتنبؤ بقيمة درجات حرارة الهواء الخارج من المجمع الشمسي قبل مرورة علي غرفة التجفيف، وكانت المعادلتين كالتالي :

$$T_{out\ (0.025)} = 4.423\ (I)^2 - 5.245\ (I) + 36.15$$

$$T_{out\ (0.015)} = 4.283\ (I)^2 - 5.335\ (I) + 34.27$$

حيث $T_{out\ (0.015)}$ ، $T_{out\ (0.025)}$ درجتي حرارة الهواء الخارج من المجمع الشمسي عند معدل سريان هوائي قدره ٠.٠١٥ ، ٠.٠٢٥ م٣/ث علي الترتيب. بينما (I) هى كمية الأشعة الشمسية الساقطة على السطح الأفقى (ميجاجول/ م٢ . ساعة).

١٠. أستنبطت معادلتين احصائيتين للتنبؤ بقيمة معدل تجفيف أوراق الريحان فى غرفة التجفيف عند أسماك مختلفة من أوراق الريحان مع معدلين من سريان الهواء فى المجنع الشمسى ، وكانت المعادلتين كالتالي:

$$D_{r\ (0.015)} = 2.511\ e^{0.102\ (D)}$$

$$D_{r\ (0.025)} = 2.638\ e^{0.103\ (D)}$$

حيث $D_{r\ (0.025)}$ ، $D_{r\ (0.015)}$ معدلى تجفيف أوراق الريحان عند معدل سريان هوائى قدره ٠.٠١٥ ، ٠.٠٢٥ م٣ / ث على الترتيب ، بينما (D) هى سمك طبقة أوراق الريحان (سم).

١١. تحت ظروف هذه التجارب، وجد أن أنسب سمك لتجفيف أوراق الريحان بالهواء المسخن باستخدام الطاقة الشمسية هو ٤ سم مع معدل سريان هواء ٠.٠٢٥ م٣ / ث فى المجمع الشمسى.