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EFFECT OF NUTURAL CONVECTION SOLAR DRYING ON QUALITY OF PEPPERMINT

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ABSTRACT

The main objective of this research work was to investigate the effect of two different natural convection solar drying systems on quality of two species of peppermint namely: mentha pepperita and mentha vridis. Two different natural convection solar drying systems namely: direct (a) and indirect (b) systems were designed and constructed with respect to their ability to dry peppermint and other medicinal plants. Both of the solar air heater and the drying cabinet were oriented to face the south direction and tilted with an optimum tilt angle at noon. The obtained results indicated that the air temperature in the dryers increased above ambient (36.4^{o}C) by maximum values of 14.2^{o}C and 9.6^{o}C for dryers (a) and (b), respectively. The daily average thermal efficiencies for dryers (a) and (b) were 36.60% and 35.70%, respectively. Dryer (a) achieved the fast rate of peppermint moisture content reduction as compared with dryer (b). On the basis of the effective collector areas, the estimated moisture removal rates were 3.57 and 3.53 kg .m^{-2} .day^{-1} for dryers (a) and (b), respectively. The water loss from mentha pepperita (72.4% w.b.) was higher than that lost from mentha vridis (65.2% w.b.). The oven drying method gave the lowest essential oil and chlorophylls A and B contents as compared with the solar drying methods. The essential oil content of dried peppermint was slightly higher for dryer (a) as compared with dryer (b), while chlorophylls A and B contents were slightly higher for dryer (a) as compared with dryer (b). The total costs of drying one tone of peppermint for the two different drying systems (a) and (b) were 52.4 And 96.7 L.E/tone, respectively. Dryer (a) may be recommended to use by small farmers for drying peppermint, medicinal plants and other agricultural products

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INTRODUCTION

Two peppermint species (Mentha pepperita and Mentha virdis) considered as the most important medicinal and aromatic plants. They are widely growing in Fayoum location, Egypt.

They mainly consumed as a fresh or in many forms (Liquid, aromatic oil, dried and dried re-hydrated with bakery products). The aromatic oil of peppermint contains many components which are used in manufacturing of pharmaceuticals for administration of many diseases such as: flu, catarrh, nerve tissue and bloating intestinal. It is, also, used in manufacturing of perfumes, soap and as a food and drink flavor.

Yaskonis and Jaskonis (1990) found that 85.5% of the planted rhizomes were rooted throughout 3-years trial with peppermint (Mentha pepperita), where the cultivar was vigorous and productive. In the 1st year, the dry leaf yield and the essential oil content of the leaves were 39 kg/ha and 2.79%, respectively, while in the 2nd and 3rd years they were 35.8 kg/ha, 2.99% and 20.0 kg/ha, 3.10%, respectively. The cultivar is recommended for growing commercially in Lithuania. **Nedkov and Georgiev (1991)** revealed that peppermint (Mentha pepperita) is a major essential oil plant. The dried leaves are used for various blends of tea which are reputed to have medicinal properties. **Chalchat and Michet (1997)** reported that pre-drying of peppermint herbage prior to distillation does not affect chemical composition and allows steam distillation of greater amounts of plant material. **Ozguven and Kirici (1999)** indicated that peppermint (Menthe pepperita) gave the highest herbage yield. The total fresh herbage, dry herbage and dry leaf yields ranged from 115.5 to 678.1, 57.6 to 322.5 and 17.0 to 133.0 kg/day, respectively. The essential oil contents varied between 1.57% and 6.29%, which were higher than the values in the pharmacopoeia because of the high temperature. The menthol content of peppermint (Mentha pepperita) cultivars ranged from 6.23% to 40.47%.

Sun drying (exposing the product being dried to direct sunrays) is still the most common method used to preserve the agricultural products in most small Egyptian farms and medicinal plants producers. This method is easy, cheep, however it is time consumed and does not guarantee clean product. **Abou-zied (1988)** indicated that the traditional drying method of peppermint can be carried out by placing 15-cm thick layer of fresh herbs on a platform at a shaded place for 7-days with daily stirring of herbs to increase the ventilation rate and leaves quality without change its color, and to prevent fermentation. Dried herbs of peppermint are preferred for obtaining high quantity and good quality of aromatic oil as compared with fresh or semi-dried helps. Therefore, the huge part of the local yield is preserved in a dried form for making different products out of the season. The traditional drying method takes long time with less drying quality and efficiency.

MWPS-22 (1981) indicated that in clear days, the maximum amount of solar energy is available at mid-day and the maximum temperature rise in a solar collector occurs near noon time. Therefore, the solar collector delivers the largest fraction of its total energy output during the period of high radiation under clear sky conditions in which about 85% of solar radiation is direct and 15% is diffuse. **Muhlbauer (1986)** reported that using the solar dryers in developing countries can reduce crop losses and improve the quality of the dried product significantly as compared with traditional drying method. **PaTil and Ward (1989)** classified the solar drying process into three modes on basis of drying air temperatures: a) natural air drying, b) supplemental heated air drying and c) heated air drying. Therefore, the drying method determines the quality of the dried product and the active ingredients contents. **Paakkonen et al. (1990)** carried out some drying experiments on peppermint (Mentha pepperita), Agastache Foeniculum, Petrosselinum Crispum and Angelica Arch angelica (grown in Finland) using near infrared drying (with a product temperature ranged from 35^{o}C to 50^{o}C) and electric oven drying adjusted at 40^{o}C. They indicated that fresh material had very poor microbiological quality. However, the quality of the fresh material was the major factor determining the quality of dried herbs. Also, they concluded that infrared radiation has potential for drying herbs, since it was gentle and shortens the processing time as compared with the oven drying method. **Sankat and Rolle (1991)** indicated that a simple natural convection dryer of the direct cabinet type was used for drying coconuts endosperm (copra) in the Trinidad, India and the drying process was completed in four days in sunshine. The cost of drying was estimated at $49 per tone. On the other hand, They concluded that the indirect solar dryers which operating by natural convection and consisting of coupled solar air heaters and drying chambers are not recommended for copra drying in these locations, due to the potential for crop spoilage resulting from stagnant conditions and moisture condensation. **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 heated air by solar energy to dry peppermint (Mentha pepperita) under Tripoli conditions, Libya. They indicated that increasing airflow rate, duct passage size of the solar collector and the peppermint depth reduce the drying time by 15% to 20%. Also, they indicated that the final dried peppermint using the heated air was clean and good quality as compared with that dried by exposing directly to sunrays. **Kassem et al. (2006)** dried some medicinal plant (lemongrass, oregano, spearmint and peppermint) using three different drying methods (solar drying at 35 ^{o}C, natural drying at 30 ^{o}C and artificial drying in oven at 45^{o}C). Their results indicated that the use of artificial drying in the oven at 45^{o}C gave the lowest values of essential oil content and the lowest chlorophyll contents for these plants as compared with the other methods. The efficiency of the dryer heat exchanger was 91.6%, 87.0%, 91.1% and 92.0% for lemongrass, oregano, spearmint and peppermint, respectively. Therefore, the aim of this study is to develop and evaluate a natural convection solar drying system of simple design, construction and operation, as well as of low initial cost for the use of small-scale Egyptian farmers.

The specific objectives of this study are to:

1. Design and construct a natural convection solar drying system able to dry aromatic and medicinal plants and test its thermal performance.
2. Investigate the factors affecting the drying process.
3. Determine the most important chemical characteristics of the dried peppermint.

MATERIALS AND METHODS

Two experimental models of natural convection solar drying system were designed and manufactured for drying peppermint. The experiments were carried out during the growing season of peppermint on August, 2007 in special farm owned by producer and exporter of aromatic and medicinal plants. This farm locates at Abchway district (مركز أبشواى), which far about 20 km from Fayoum city, Egypt. The latitude angle at Fayoum and the solar altitude angle at noon on August are 29.3^{o} N and 74.2^{o}, respectively. The experiments were completely financed by the owner of the farm.

A. Description of the Solar Drying Units:

Two natural convection solar drying systems of simple design for use by small farmers in Egypt were constructed for drying the aromatic and medicinal plants and other agricultural products. No electrical energy input used with these dryers to make them more applicable in the remote areas and the new reclaiming areas. A schematic diagram for the two solar dryers is shown in (Fig.1). One of the two dryers was direct dryer type (Fig. 1a) and the second was indirect dryer type (Fig. 1b), and the following are detailed of their components:

1. Direct solar Drying system: This dryer was designed specifically for drying the aromatic and medicinal plants by small farmers (Fig. 1a). Simplicity in design, low cost and ease of construction were the essential elements in the design considerations. It made of wooden-sided frame (2.40 m long, 1.17 m wide and 0.35 m deep) to form the drying cabinet. A 5-mm thick of granular wood was used to cover the cabinet bottom at which the product being dried was placed. A clear transparent plastic cover was used to fit snugly over the sides of the cabinet. One long side of the cabinet was used as a door (2.40 m × 0.25 m) for handling the product being dried. The drying cabinet cover is made of wooden frame at which the clear transparent plastic sheeting was attached. All the cabinet and cover frames were painted from inside and outside surfaces using matt black paint. The drying cabinet was insulated from the bottom using a 5-cm thick of glass wool to minimize the heat losses to the ambient atmosphere. Screened galvanized flat metal plate (absorber plate) painted black was located at 0.05 m from the cabinet top and 0.25 m over the cabinet bottom. The holes percentage per the absorber plate is 40%. Screened air inlet and exit ports (1.17 m × 0.05 m) were provided at the front and rear ends of the drying cabinet.

2. Indirect solar drying system: This system consists of solar air heater attached with drying chamber (Fig. 1b). The solar air heater is rectangular in shape and made of wooden box and single transparent plastic cover flat-plate with airflow by natural convection over the absorber. It is having a surface area of 2 m^2 (2 long and 1 m wide) and duct passage of 0.10 m deep. It was painted from inside and outside surfaces using matt black paint. The bottom and the sides of the solar air heater were insulated using 5 cm thick of fiber-glass wool has a thermal conductivity of 0.045 W/m ^oC (PaTil and Ward, 1989). To minimize the reflection of radiation and reduce heat losses by convection, a clear transparent plastic material was situated to cover it. The drying chamber is made of wooden frame (1.0 m long, 0.50 m wide and 1.0 m deep). The drying chamber was designed to hold four drying trays (0.95 m long, 0.45 m wide and 0.20 m deep) stacked vertically. The drying trays were made of an iron frame on all four sides and 0.15 cm mesh stainless steel wire screen. Air inlet at the front of the solar air heater was rectangular opening (1.0 m×0.10 m) covered by screen. The heated air naturally entered the drying chamber below the drying trays and flowed upwards through the drying trays, and after that leaving through the exhaust system (chimney). The chimney was protected by a cover to prevent the cold air from entering the drying chamber and to maintain the temperature of the drying chamber at the ambient temperature when the drying process was off. Simultaneously, the air inlet duct of the solar air heater was, also, closed using handling unit. The drying trays were removed or inserted into the drying chamber through a hinged door at the back side, which was sealed tightly during the drying process.

All the drying cabinet (direct dryer a) and the solar air heater (indirect dryer b) were supported from one end on a movable stands for obtaining the desired optimum tilt angle during the months of the year. Both of them were oriented to face the south direction and tilted at an angle of 15.8^o from the horizontal plane, which was determined as a function of latitude and declination angles to be an optimum tilt angle at noon (**B**) for the specific location and time of the year according to Duffie and Beckman (1991) using the following equation:

B = Latitude angle (Φ) – solar declination angle (δ) , (°) ... (1)

Where:

Φ = Latitude angle at Fayoum is 29.3° N.

δ = Solar declination angle = 23.45 sin [0.9863 (n + 284)] = 13.5 °.

n = number of the day from the first of January, 228 for August.

B = 29.3 - 13.5 = 15.8 °

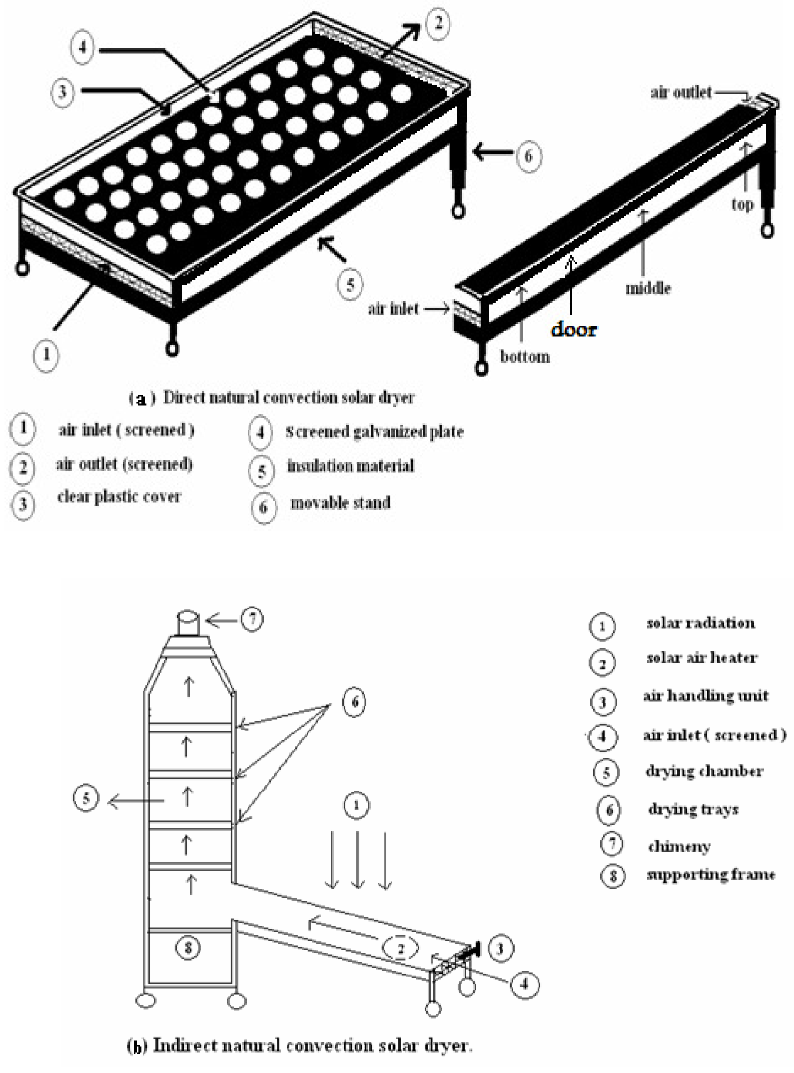


Figure (1): Schematic diagram of experimental set-up.

B. Measuring Instrumentation:

1. Solar radiation measurement: The total solar radiation flux incident on the horizontal surface (W/m^2) was measured using a radiometer (model 8-8 serial No. 14046). The solar radiation incident on the tilted surfaces of the solar air heater (indirect dryer) and the drying cabinet (direct dryer) was computed according to Duffie and Beckman (1991). The hourly total solar radiation incident on a tilted surface (I_T), is the sun of three components: beam radiation, diffuse sky radiation and reflected radiation from the ground. Thus, for a solar collector surface facing south and tilted at slope angle (β) from the horizontal, the incident total radiation ($I_{d,t}$) is given by the following equation:

$$\mathbf{I_T = I_{b,t} + I_{d,t} + I_{g,t}} \quad \text{...} \quad \mathbf{(2)}$$

Where:

I_T is the hourly total radiation on a tilted surface and $I_{b,t}$, $I_{d,t}$ and $I_{g,t}$ are the hourly beam, diffuse and reflected radiation on a tilted surfaces, respectively (W/m^2).

The hourly beam radiation on a tilted surface can by estimated from the hourly beam radiation on the horizontal (I_b) as follows:

$$\mathbf{I_{b,t} = I_b \, . \, R_b} \quad \text{..} \quad \mathbf{(3)}$$

Where:

I_b is the hourly beam radiation on the horizontal (W/m^2) and R_b is the ratio of beam radiation on a tilted surface to that on a horizontal surface (-) .

The ratio (R_b) was calculated for the collector facing south as follows:

$$\mathbf{R_b = \frac{\cos(\Phi - \beta)\cos\sigma\cos w + \sin(\Phi - \beta)\sin\sigma}{\cos\Phi\cos\sigma\cos w + \sin\Phi\sin\sigma}} \quad \text{...} \quad \mathbf{(4)}$$

The hourly beam radiation on the horizontal (**I_b**) can by calculated by subtracting the hourly diffuse radiation from the hourly total radiation as follows:

$$\mathbf{I_b = I - I_d} \quad \text{..} \quad \mathbf{(5)}$$

Where:

I, I_d are the hourly total and diffuse solar radiation on a horizontal surface, respectively, (W/m^2).

The hourly diffuse sky radiation on the tilted surface ($I_{d,t}$) was calculated from the hourly diffuse radiation on a horizontal surface as a function of the collector slope angle as follows:

$$I_{d,t} = I_d \left(\frac{1+\cos\beta}{2} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

The hourly reflected radiation from the ground ($I_{g,t}$) was estimated from the hourly total radiation on the horizontal using the following equation:

$$I_{g,t} = I\, pg \left(\frac{1-\cos\beta}{2} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Where:

p_g is the ground diffuse reflectance.

The total solar radiation incident on the tilted surface (I_T)for an hour as the sum of the three components can be written as follows:

$$I_T = I_b R_b + I_d \left(\frac{1+\cos\beta}{2}\right) + (I_b + I_d)\ p_g \left(\frac{1-\cos\beta}{2}\right) \quad \ldots(8)$$

2. Temperature measurement: The temperatures at different points were measured using copper-constantan thermocouples. The thermocouples were calibrated at both boiling and freezing points. The measurements were conducted using digital thermometer (model Omega type J, USA).

3. Airflow rate measurement: The inlet air speeds (m/s) at both of the air inlet ducts of the drying cabinet (direct dryer a) and the solar air heater (indirect dryer b) were measured using a hot wire anemometer (model TESTO-425, Germany), which has accuracy of ± 0.01 m/s. The measured values were multiplied by the area of each air inlet duct to obtain the volumetric airflow rate m^3/s.

4. Relative humidity measurement: The air relative humidity (%) of the ambient atmosphere and the air inlet and outlet ducts of each dryer was measured using thermo-hygrometer (model 37200, OKTON).

5. Moisture content measurement: An electric balance and electric oven were used for weighing and drying samples determine the moisture content of both fresh and dried peppermint during the drying process. The capacity of the electric balance was 1 kg with accuracy of ± 0.01g. Samples of approximately 10 to 15 grams were taken every 2 hours interval and dried on the electric oven at 70°C for 24 hrs. The moisture content was calculated on both wet and dry bases (ASAE, 1991).

C. Thermal Performance of Solar Dryers:

The thermal performance of the solar drying systems was estimated according to Duffie and Beckman methods (1991), using the following equations:

1. Available solar energy (Q_{av}): The total solar radiation available on the specific tilted surfaces of the drying cabinet and the solar air heater is calculated using the following formula:

$$Q_{av} = I_T \times A_C, \quad \text{(Watt)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

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. Absorbed solar radiation (Q_{ab}): The absorbed solar radiation by both of the drying cabinet and the solar air heater is calculated as follow:

$$Q_{ab} = Q_{av} \times (\tau\alpha) = (I_T \times A_C) \times (\tau\alpha), \quad \text{(Watt)} \quad \ldots.. (10)$$

Where:

$(\tau\alpha)$ is the transmittance-absorptance product, (-).

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

$$Q_{us} = m\ Cp\ (T_{ao} - T_{ai}), \quad \text{(Watt)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where:

m is the air mass flow rate, (kg/ s).

Cp is the specific heat of air, (kJ/kg .°C).

T_{ao} and T_{ai} are the outlet and inlet air temperatures of the solar air heater and the drying cabinet, (°C).

4. The thermal efficiency of the solar collector (η_{th}): The thermal efficiency for both of the drying cabinet and the solar air heater is calculated as follows:

$$\eta_{th} = Q_{us} / (I_T \times A_C) = [m\ Cp\ (T_{ao} - T_{ai})] / (I_T \times A_C), \quad (\%) \ldots(12)$$

D. Chemical Analysis:

The chemical analysis was performed on both fresh and dried peppermint samples in order to determine the essential oil, chlorophyll (A) and chlorophyll (B) contents. The essential oil of peppermint herbs was determined according to the method described in the British

Pharmacopoeia (1963). Chlorophyll (a) and chlorophyll (b) contents were determined according to the method mentioned by Saric et al (1967).

E. Experimental Procedure:

Tow peppermint species (Mentha pepperita النعناع الفلفلى and Mentha virdis النعناع البلدى) were collected from special farm, in which the experiments were carried out. At the beginning of the experiments, the initial moisture content of fresh peppermint were determined and found to be 76% and 82% for mentha pepperita and mentha virdis, respectively. For each drying run, the peppermint thickness was 6-cm and drying began at 8:00 am on the first day and continued to 8:00 pm on the second day. At night, the two dryers were left unmodified, where the air inlet and outlet ducts were handily closed. At the beginning of each drying run, the masses of labeled peppermint samples were measured initially and every six hours intervals each day, while the air temperatures and insolation were measured at hourly intervals. The dry weights of the corresponding peppermint samples were determined after oven drying at 70^{o}C for 24 hours. From this data, the moisture content, essential oil (%) and chlorophylls (A) and (B) of peppermint during the drying process were determined.

RESULTS AND DISCUSSIONS

In examine the thermal performance of the natural convection solar drying systems, the following parameters were evaluated:

1. Solar radiation. 2. Air temperature. 3. Drying rate.
4. Chemical analysis. 5. Dried product quality. 6. Drying cost.

1. Solar Radiation: The hourly average total solar radiation incident on the horizontal surface at Fayoum, Egypt (latitude 29.30^{o} N) on August (2007) were measured. The hourly average solar radiation incident on the tilted surface and that absorbed by the absorber plate of the drying cabinet (direct dryer a) and the solar air heater (indirect dryer b) were estimated according to Duffie and Beckman (1991) and the results are listed in Table (1). Both the drying cabinet and the solar air heater having the same surface area of 2.0 m^{2}. They were oriented with an optimum angle of 15.8^{o} to maximize the solar radiation flux incident at and around noon. The results indicated that the daily average total solar radiation flux incident on the tilted surfaces of the solar air heater and the drying cabinet was 17.486 kWh/day. Meanwhile, the daily average total solar radiation available on the horizontal plane was 16.322 kWh/ day. Consequently, the tilted surfaces of the drying cabinet and the solar air heater increased the solar energy available by 7.1%. The daily average absorbed solar energy was 13.994 kWh/day with absorption efficiency of 80.03%. Thus, for the purpose of solar drying, maximum energy collection is desired for a given month to maximize the amount of solar energy gained by the drying unit.

Table (1): Hourly average total solar radiation for Fayoum, Egypt on August, 2007.

Solar time (h)	Solar radiation flux incident on the horizontal and tilted surfaces			Absorbed solar energy
	I_n (W/m²)	Q_{hsc} (Watt)	Q_{tsc} (Watt)	Q_{ab} (Watt)
8	389.6	779.2	832.2	687.4
9	598.4	1196.8	1280.6	1057.8
10	847.8	1695.6	1814.3	1498.6
11	926.3	1852.6	1985.9	1640.4
12	988.7	1977.4	2133.2	1762.0
13	962.6	1925.2	2063.8	1704.7
14	884.3	1768.6	1894.2	1564.6
15	736.0	1472.0	1575.0	1301.0
16	648.2	1296.4	1385.9	1144.8
17	562.4	1124.8	1203.5	994.1
18	333.6	667.2	713.2	589.1
19	283.1	566.2	604.7	499.5
Total	8161.0	16322.0	17486.1	13994.0
Mean	680.1	1360.2	1457.2	1166.2

I_n = hourly average total radiation incident on the horizontal surface (W/m²).
Q_{hsc}= hourly average total radiation incident on horizontal plane of solar air heaters (W).
Q_{tsc} = hourly average total radiation available on tilted surfaces of air solar heaters (W).
Q_{ab} = hourly average total radiation absorbed by the air solar heater and drying cabinet (W).

The daily average total heat energy gained and overall thermal efficiency for the two solar drying units were calculated for six successive days of the drying process on August (2007) and the results are listed in Table (2). During this period, insolation average was 8.20 kW/m^2 day with range of 7.88 kW/m^2.day on the third day to a peak of 8.46 kW/m^2.day on the fifth day. The obtained results almost clarified the same trend of that obtained for hourly average and revealed that, the daily averages total useful heat energy gained of the drying cabinet (direct dryer a) and the solar air heater (indirect dryer b) were 6.42 and 6.27 kWh/day, respectively. The daily average total radiation available on the tilted surfaces was 17.55 Kw/day. Therefore, the daily average overall thermal efficiencies for the two drying units were 36.6% and 35.7%, respectively. Consequently, the direct solar drying unit (drying cabinet) increased the overall thermal efficiency by 0.90 % as compared with the indirect solar dying unit.

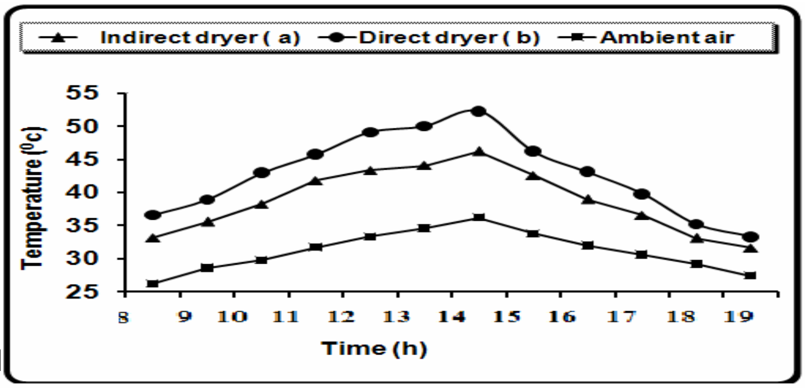
Table (2): Daily average heat energy gained and overall thermal efficiency of the solar collectors at different days of August, 2007.

Date of experiment	Incident, available and absorbed solar radiation				Energy gained and thermal efficiency			
					Solar drying units			
	I_n kW/m^{2}day	Q_{hsc} (kW/day)	Q_{tsc} (KW/day)	Q_{ab} (KW/day)	Direct solar dryer		Indirect solar dryer	
					Q_{us} (KW/day)	η (%)	Q_{us} (KW/day)	η (%)
3/8	7.97	15.94	17.06	14.09	6.28	36.8	6.20	36.3
4/8	8.22	16.44	17.56	14.40	6.45	36.7	6.31	35.9
5/8	7.88	15.76	16.91	13.70	6.06	35.8	5.73	33.9
6/8	8.32	16.64	17.79	14.69	6.55	36.8	6.46	36.3
7/8	8.46	16.92	18.10	14.95	6.70	37.0	6.54	36.1
8/8	8.36	16.72	17.89	14.53	6.48	36.2	6.39	35.7
Average	8.20	16.35	17.55	14.40	6.42	36.6	6.27	35.7

I_n = Daily average total radiation incident on the horizontal surface (kW/m^2 day).
Q_{hsc}= Daily average total radiation incident on horizontal plane of solar air heaters (kW).
Q_{tsc} = Daily average total radiation available on tilted surfaces of the solar air heaters (kW).
Q_{sb} = Daily average total radiation absorbed by the absorber plates of solar air heaters (kW).
Q_{us} = Daily average total radiation gained by the solar air heaters (kW).

2. Drying Air Temperature: The dry-bulb temperatures of the two solar natural convection drying systems were measured at hourly intervals between 8.0 am and 7.0 pm for the six full days of drying process and the results are shown in Fig. (2). The hourly average ambient temperature was increased gradually from 26.2^{o}C at 8.0 am until reached its maximum value of 36.4 at 2.0 pm, while the air relative humidity was decreased from 66.2% at 8.0 am to its minimum value of 35.3% at 2.0 pm.

Temperatures in the direct solar dryer (a) were usually 4 – 6 ^{o}C higher than those in the indirect solar dryer (b). Fig. 3 (a and b) show the temperature variability within the two solar dryers, where air temperatures between 8.0 am and 7.0 pm at various points in the two dryers and averaged over six full days of drying process. The direct solar dryer (dryer a) showed the widest variation in air temperature, whereas the highest temperatures were obtained in its middle rather than at the top. This probably due to the infiltration of the prevailing winds through the air exit at the top of this dryer. In the indirect solar dryer (dryer b), the highest air temperature was achieved on the lowest tray (nearest to the air solar heater), and the temperature profiles indicate an expected behavior in that as the air rose through the trays it lost enthalpy to evaporation and consequently the air temperature decreased.



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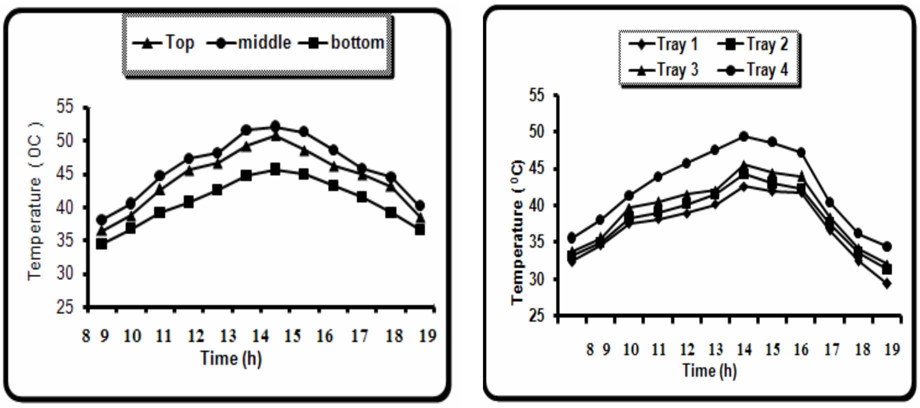
two solar dryers and ambient air temperature.



(a) Direct solar dryer **(b) Indirect solar dryer**

Fig. (3). Hourly average temperature variations in the two solar dryers.

3. Peppermint Drying Rate: The moisture content of two peppermint species (dry-basis), for the two solar drying systems at various locations and for the two drying days are given in Tables 3 and 4. The moisture content reported are the mean values obtained from the individual samples in a particular tray or location i.e. six samples per tray in the indirect solar dryer (dryer b), and six, seven, six samples from the top, middle and bottom sections respectively for the direct solar dryer (dryer a). These tables also show the average moisture content of two peppermint species with time (mean of all samples) for the two dryers.

Table (3): Estimated peppermint moisture content (dry-basis) for the indirect solar dryer (dryer b).

Day	Time (h)	Moisture content (% d.b.)			Average moisture content (% d.b.)
		Top	Middle	Bottom	
		Mentha pepperita			
1	8:00	455.6	455.6	455.6	455.6
	14:00	246.8	204.9	228.9	226.9
	20:00	127.2	108.6	118.9	118.2
2	8:00	117.8	100.3	112.2	110.1
	14:00	63.1	58.2	61.8	61.0
	20:00	11.3	10.0	10.8	10.7
Mentha virdis					
1	8:00	316.7	316.7	316.7	316.7
	14:00	184.3	177.8	182.5	181.5
	20:00	111.2	100.6	108.7	106.8
2	8:00	109.8	99.1	106.6	105.0
	14:00	65.7	56.3	63.8	61.9
	20:00	12.6	11.2	12.3	12.0

Table (4): Estimated peppermint moisture content (dry-basis) for the direct solar dryer (dryer a).

Day	Time (h)	Moisture content (% d.b.)				Average moisture content (% d.b.)
		Mentha pepperita				
		Tray 1	Tray 2	Tray 3	Tray 4	
1	8:00	455.6	455.6	455.6	455.6	455.6
	14:00	257.2	267.5	266.9	261.4	263.3
	20:00	127.3	131.6	129.8	128.1	129.2
2	8:00	126.6	130.1	128.6	127.3	128.2
	14:00	66.7	63.6	65.1	64.2	64.9
	20:00	11.1	11.9	12.6	11.8	11.8
Mentha virdis						
1	8:00	316.7	316.7	316.7	316.7	316.7
	14:00	212.5	216.8	226.1	229.3	221.2
	20:00	115.5	121.2	118.3	116.4	117.9
2	8:00	113.8	116.9	117.1	115.8	115.9
	14:00	68.9	72.6	70.3	69.7	70.4
	20:00	12.8	12.6	13.3	12.7	12.9

From these tables, Figure (4) was constructed and it shows the changes in the peppermint moisture content ratio (variable moisture content (M)/ initial moisture content (M_o)) with the drying time. The results in Figure (4) indicated that in the initial period of drying, the rates of peppermint moisture content reduction for the two dryers are very similar but the direct solar dryer shows the highest moisture content reduction as compared with the indirect solar dryer. This behavior is due to the increased air temperature in the direct solar dryer as compared with that in the indirect solar dryer as previously mentioned. The horizontal segment in Fig. (4) indicate that no drying at night, in the latter half of the drying cycle. Abdel-Galil and Tarhuni (2005) clearly demonstrated the strong influence of drying air temperature on the rate of peppermint drying. From the data of Tables 3 and 4 with the initial peppermint weight (20 kg fresh peppermint for each dryer), the average moisture removal rates from the peppermint over the two full days of drying are estimated as 7.14 and 7.06 kg H_2O /day for the dryers (a) and (b), respectively. By dividing these rates on an effective collector area basis (2.0 m^2 for each dryer), then they are 3.57 and 3.53 kg H_2O/m^2.day for dryers (a) and (b) respectively. These results show that while the absolute moisture removal rates are not different for the tow dryers, the direct solar dryer (dryer a) is marginally effective. Regardless of the drying method, it obvious from Figure (5) that the percentage of water loss from peppermint depends on the nature of the herb. Therefore, the water loss from mentha vridis (65.2%) was the lowest as compared with that loss from mentha pepperita (72.4%).

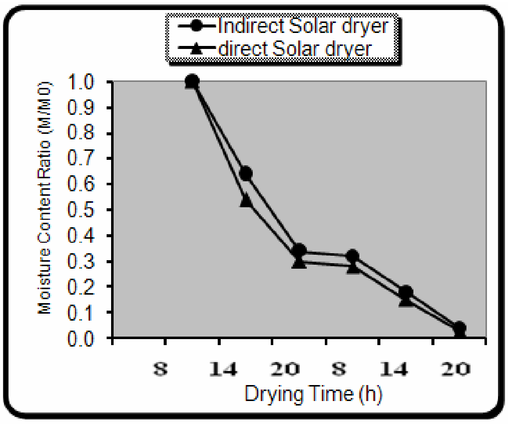


Fig. (4): Drying curves for peppermint in the two dryers.

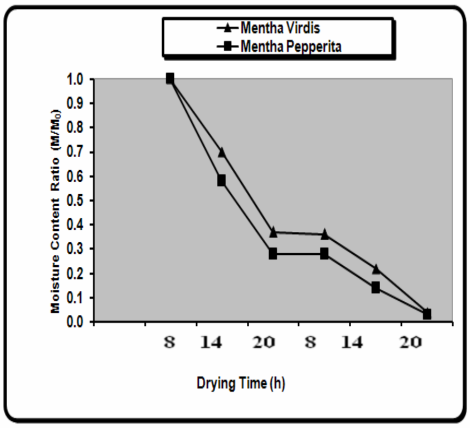


Fig.(5): Drying curves of two peppermint species in dryer (b).

4. Chemical Analysis of Peppermint: The results in Table (5) show that the essential oil content of fresh mentha pepperita (2.89%) was higher than that of fresh mentha vridis (2.56%), while on contrast chlorophyll (A & B) contents of fresh mentha pepperita (6.77 and 4.20 mg/g) were lower than those of fresh mentha virdis (9.86 and 5.78 mg/g). Regarding to the influence of the drying method on both of essential oil and chlorophyll (A & B) contents of dried peppermint, the results in Table (5) show that the oven drying method was the most harmful method, since it destroyed the huge amount of the essential oil and chlorophyll (A & B) contents. On the other hand, the direct solar dryer (dryer a) proved to be the most proper method in this regard to dry peppermint followed by the indirect solar dryer (dryer b).

Table (5): Chemical analysis of peppermint as affected by the drying method.

Drying method	Mentha pepperila			Mentha virdis		
	Essential oil (%)	chlorophyll		Essential oil (%)	chlorophyll	
		(a)	(b)		(a)	(b)
Fresh peppermint	2.89	6.77	4.20	2.56	9.86	5.78
Direct solar dryer	1.76	4.10	1.96	1.48	7.12	3.42
Indirect solar dryer	1.64	3.54	1.82	1.37	6.58	3.27
Oven	0.86	2.26	0.89	0.74	3.16	1.36

5. Dried peppermint Quality: The two solar dryers produced good, clean and green peppermint because they provide isolated atmosphere and suitable drying temperatures which minimize the contamination of the dried product. The dried peppermint using direct solar dryer (dryer a) was very good quality, since it kept its essential oil content and chlorophyll (A & B) contents slightly higher than that dried by the indirect solar dryer (dryer b).

6. Dryers Cost: Direct and indirect solar dryers (dryers a & b) are currently cost 505 L.E and 760 L.E, respectively. These costs reflect the considerable reduction in material and labor required for constructing the direct solar dryer (dryer a). Neglecting the differences in the time required for a batch of peppermint, it is therefore expected that the annual throughput of the direct solar dryer (dryer a) will be approximately twice as much as that of the indirect solar dryer (dryer b).

In the basis of initial cost, an expecting dryer life of 5 years and an annual throughput which assumes a drying season of 30 weeks/year which drying occurring in weekly batches, it is estimated that the drying cost for medicinal plants will be 52.4 L.E and 96.7 L.E per tone for the direct and indirect solar dryers (dryers a & b), respectively. For the direct solar dryer (dryer a), the cost includes the expected replacement of the plastic cover at 15 weeks intervals during the drying season.

CONCLUSION

The obtained results from this investigation can be concluded as follows:

1. The two natural convection solar dryers used in this study provide isolated atmosphere that minimize the contamination of the dried product, and they were sufficient for drying 40 kg of peppermint in two days of sunshine.
2. The hourly average drying air temperatures in the direct solar dryer (dryer a) were usually 4-6^{o}C higher than those of the indirect solar dryer (dryer b) with the difference in temperature between the direct solar dryer and the ambient peaking at 16^{o}C between 12:00 noon and 2:00 pm.
3. The daily average overall thermal efficiencies for both of the direct and indirect solar dryers were 36.60% and 35.70%, respectively.
4. The direct solar dryer (dryer a) gave the highest moisture content reduction of peppermint as compared with the indirect solar dryer (dryer b).
5. On the basis of the effective collector areas, the estimated moisture removal rates were 3.57 and 3.53 kg H_2O. m^{-2}. day^{-1} for dryers (a and b), respectively.
6. The water loss from mentha pepperita (72.4%) was the highest as compared to that lost from mentha vridis (65.2%) for the two dryers at the same drying period.
7. The two species of peppermint dried by the two solar drying methods kept their essential oil contents as high as possible.
8. For the two species of peppermint used in this study, the essential oil content was slightly higher using the direct solar dryer (dryer a) as compared with that obtained from the indirect solar dryer (dryer b).

9. Chlorophyll (A and B) contents of dried peppermint were slightly lower by using the direct solar dryer (dryer a) as compared with those obtained from the indirect solar dryer (dryer b), although they gave approximately the same green color.
10. The total costs of drying one tone of peppermint for the direct solar dryer (dryer a) was 52.4 L.E/tone compared to 96.7 L.E/tone for the indirect solar dryer (dryer b).

RECOMMANDITIONS:

1. The natural convection solar dryer of the cabinet type as exemplified by dryer (a) in this study can be used by small farmers in Egypt for the drying of peppermint, medicinal plants and other agricultural products because it is cheap, simple to construct, possibly by the farmer himself and using material which readily available.
2. For such dryers to be effective, air flow should be maintained at night, possibly through thermal storage as a rock bed.

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<u>الملخص العربى</u>

تأثير التجفيف الشمسي ذو الحمل الطبيعي على جودة النعناع

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أجرى هذا البحث بغرض تصميم وإختبار نظام للتجفيف الشمسى ذو الحمل الطبيعيى وتأثير ذلك على جودة النعناع المجفف، حيث تم تصميم هذا النظام وإختباره وتنفيذه فى مزرعة خاصة بناحية مركز أبشواى– محافظة الفيوم، وهذه المزرعة ملك لأحد كبار المنتجين والمصدرين للنباتات الطبية والعطرية والذى قام بتمويل هذا البحث على نفقته الخاصة.

يتكون هذا النظام من وحدتين تجفيف شمسى منفصلتين تعملان بتيارات الحمل الطبيعية ، الوحدة الأولى لمجفف شمسى مباشر والذى يتكون من هيكل لغرفة تجفيف صغيرة مطوق بإطارات من الخشب (2.4× 1.17×0.35 متر) ، حيث تم تبطين قاعدته بالخشب ومواد عزل حرارى بسمك 5سم وغطيت الجوانب بالبلاستيك الأبيض الشفاف، ومثبت على الجوانب من الداخل لوح مثقوب من الصاج المجلفن على إرتفاع 20 سم من قمة الهيكل الخشبى لوضع المنتج المراد تجفيفه لكى يسمح للهواء بإخيراقه من أعلى ومن أسفل، أما الغطاء فهو عبارة عن إطار من الخشب مغلف بلوح من البلاستيك الأبيض الشفاف، ويوجد بغرفة التجفيف

فتحتان مقاس كل منهما 1.17×0.1 متر مثبت عليهما سلك شبكى (غربال) إحداهما فى مقدمة غرفة التجفيف من أسفل لدخول الهواء والأخرى فى مؤخرتها من أعلى لخروج الهواء. أما الوحدة الثانية فهى لمجفف شمسى غير مباشر والذى يتكون من جزئين رئيسيين هما سخان الهواء الشمسى (2× 1× 0.1 متر) الذى فيه يتم تسخين الهواء ثم دفعه بفعل الحمل الطبيعى إلى الجزء الثانى وهو غرفة التجفيف الرئيسية والتى تم تزويدها بأربع صوانى مصنوعة من هياكل حديدية وشباك بلاستيكية لكى تسمح للهواء بإختراق المنتجات المراد تجفيفها متماثلة.

<u>وقد أوضحت نتائج الدراسة ما يلى:</u>

1. وفر المجمعين الشمسيين بيئة معزولة عن الجو الخارجى والتى بدورها قللت كثيرا من تلوث المنتج المجفف ، وكانا كافيين لتجفيف 40 كجم من النعناع الأخضر خلال يومين فقط.
2. كان المتوسط اليومى لدرجات حرارة هواء التجفيف فى المجفف المباشر (مجفف أ) 4-6 ° م أعلى من مثيلتها فى المجفف الغير مباشر (مجفف ب) ، ووصل الفرق الى حوالى 16 ° م أعلى من درجة حرارة الجو المحيط فى الفترة من 12 ظهرا إلى 2 بعد الظهر.
3. كان المتوسط الكلى للكفاءات الحرارية فى اليوم للمجففين الشمسيين المباشر والغير مباشر36.60%، 35.70 % على الترتيب.

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4. أعطى المجفف الشمسى المباشر أعلى فقد فى المحتوى الرطوبى للنعناع مقارنة بالمجفف الشمسى الغير مباشر، حيث كان معدل فقد الرطوبة من المجمعين المباشر والغير مباشر 3.57 كجم ماء/ م^2 . يوم ، 3.53 كجم ماء/ م^2 . يوم على الترتيب.
5. كان متوسط نسبة فقد الماء من النعناع البلدى (mentha pepperita) 72.4% بينما كان 65.2% للنعناع الفلفلى (mentha vridis) فى المجففين عند نفس فترة التجفيف.
6. أدى إستخدام هذا النظام فى التجفيف إلى الحفاظ على محتوى الزيوت الطيارة عند أعلى قيمة ممكنة، ولكن كانت نسبة الزيوت الطيارة فى النعناع المجفف بإستخدام المجفف المباشر أعلى نسبيا من مثيلتها فى النعناع المجفف بإستخدام المجفف الغير مباشر.
7. أعطى المجفف المباشر قيم أعلى لمكون كلوروفيل (أ ، ب) مقارنة بالمجفف الغير مباشر.
8. بحساب تكلفة تجفيف الطن الواحد من النعناع فكانت 52.40 جنية / طن للمجفف المباشر بينما كانت 96.70 جنية / طن للمجفف الغير مباشر.

<u>التوصيات:</u>

1. يوصى بإستخدام المجفف الشمسى المباشر لصغار المزارعين لأنه بسيط التركيب ورخيص التكلفة وسهل التشغيل ويمكن تصنيعه بواسطة المزارع نفسه من الخامات المتوفره محليا.
2. لزيادة كفاءة هذا النوع من المجففات، يجب تزويدها بوحدة تخزين حرارى للطاقة الشمسية بالنهار للإستفادة منها ليلا فى عملية التجفيف ويمكن تحقيق ذلك بالمرقد الصخرى.