Augmented Solar Chimney With Unglazed Perforated Passive Solar Dryer (UPPSD) For The Medicinal Plants

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Abstract: The effect of coupling solar chimney with the unglazed perforated passive dryer (UPPSD) used for drying medicinal plants was investigated. The passive drying system comprised solar chimney instead of the blower in the active dryer. Black PVC tube of 3mm thick and 127mm diameter, 4m high was installed above unglazed perforated passive dryer of 0.75m from the ground base. Holes diameters of 2mm were performed for both of the active and passive systems. The common shaded drying house (SDH) was used to compare the passive unglazed perforated solar dryer with chimney (UPPSD) and active system with suction airflow rate of $0.06m^3s^{-1}$. The pressure drop due to the chimney presence was determined beside the air velocity and Reynolds number, temperatures of air and drier surfaces for the UPPSD which was assured with a visualized smoke test were considered. Henna medicinal plants (*Lowsonia inermis L.*) were used to be dried in this investigation with the different drying methods and techniques. Drying processes were carried out under the climatic weather conditions of Ismailia, Egypt. Drying rate and ratio, the medicinal plants quality and drying costs were addressed, for the medicinal plants in different drying methods.

Keywords: Solar chimney, Unglazed perforated passive solar direr, Active drying, Pressure drop, Surface and air temperatures.

INTRODUCTION

Egypt is one of the developing countries where solar energy is generally abundantly available almost all the year round. The natural direct sunrays drying methods have many disadvantages for medicinal plants. It affects on the quality degradation, beside a large area is required. The drying time is relatively long, leading to changes and damages not only to sensory and chemical properties, but also to degrade in the storage period for these plants (Abdel-Ghaffar *et al.*, 2004).

Henna has different medicinal applications and usage. Distribution of the effective components in Henna leaves was carried out in a trial towards utilization of these components as a food preservative by Shatta, (1987). Henna leaves were extracted and analyzed for these components of the practical interest namely (Lowsone, Tannis and Phenolic compounds). The extract was fractionated by Thin Layer Chromatography (TLC) and the isolated components were tested for their anti-microbial action in different media and different PH values. Important of such components appears for the commercial producers of such plants. The production of One Fedan ($4200m^2$) cultivated by Henna under the Egyptian conditions produces in average from 700 to 800kg dry leaves, increases by 25% yearly till reaching 1000 to 1500kg/year/fed in the 5^{th} year according to Kotb (1981), Abozeid (1988) and Ahmed *et al.* (1993).

The unglazed transpired solar drying concept was used for drying as a way to cut the energy requirements and for medicinal plants higher quality. Hassanain (2004) investigated the thermal performance of the unglazed transpired active solar dryer. The study did not address the drying rate, ratio, costs or quality of the dried plants, while it focused on the thermal performance of the drying system and its thermal efficiency. In another following study Hassanain (2005) dried three medicinal plants named henna, rosemary and marjoram in that system compared to the direct sun drying and shaded drying house. The study recommended using the passive systems in the future generation of the commercial unglazed transpired solar dryers to reduce the operating cost by cutting down the consumed energy that is required for operating the suction fan. To achieve this goal, a study on the suitability unglazed perforated passive dryer should be considered.

Active solar dryers being used to dry the medicinal plants have some advantages i.e. reduce the drying air temperature not to exceed the permitted level for affecting the volatile oils or the medicinal chemical components, at the same time it is energy consuming. A solar chimney enhances natural convection drying (passive dryer) by inducing a pressure difference between the inlet and outlet via the drying system. As a result of the solar chimney effect, low relative humidity air flow is induced through the drying chamber. The heated air is passed over the medicinal plant in the drying chamber, removing water vapor. Some dryers have very short chimneys (i.e., 0.10m) above the drying chamber, resulting in a very low pressure head, Ekechukwu (1994). If the chimney wall was clear with an absorbing surface inside, it should be oriented appropriately to maximize absorption of solar radiation to maintain mean chimney temperatures above ambient temperature. Experiments were undertaken by Ekechukwu and Norton (1997) on two cylindrical polyethylene solar chimneys to study the performance of two drying design options. Each was consisting of 5.3 m high and 1.64 m diameter attached to the drying chamber. The chimney was supported structurally by steel framework and draped internally with selectively-coated absorbing surface, with and without selective surface type.

NOMENCLATURE

D	Chimney inner diameter, m	v	Air velocity, m/s
f^*	Proportional factor	v_w	Wind speed, m/s
g	Gravity of acceleration, m/s^2	β	Bulk coefficient of expansion of air, 1/°C
H	Chimney height, m	ρ	Density, kg/m^3
P_b	Buoyancy pressure drop, Pascal	ρ_a	Ambient air density, kg/m^3
Rh	Relative humidity, %	ρ_{ch}	Density for chimney air, kg/m^3
T	Temperature, °C	$\bar{\rho}_{ch}$	Chimney mean air density, kg/m^3
T_a	Ambient temperature, °C	ρ_o	Outlet air density, kg/m^3
T_{ch}	Chimney air temperature, °C		

Theoritical background for the chimney role in passive drying

The following background expresses the chimney effect to enhance the passive drying process. The buoyancy force required to generate the air flow through the chimney is directly proportional to the difference between the mean air density within the chimney and the ambient air density, represented as (Sodha *et al,* 1987);

$$\Delta P_b = gH(\rho_a - \bar{\rho}_{ch}) \qquad (1)$$

Air densities are related to air temperatures and humidity ratios (Sodha *et al,* 1987),

$$\rho = \rho_o(1+T/273)^{-1}(1+Rh) = \frac{\rho_o(1+Rh)}{(1+\frac{T}{273})} \qquad (2)$$

If the chimney interior has the same temperature and humidity conditions, and thus the same density as the ambient air, and there is no wind to produce a Bernoulli effect, then there would be no flow through the chimney. The pressure difference due to the buoyant pressure head is given by (Brenndorfer, *et al,* 1985),

$$\Delta P_b = gH(\rho_a - \bar{\rho}_{ch}) = \beta g H \rho (T_{ch} - T_a) \qquad (3)$$

Over the temperature range 25°C to 90°C (within which natural-circulation solar-energy dryers would operate), the density of dry air is related to the temperature by the following empirical expression (Brenndorfer *et al,* 1985),

$$\rho = 1.11363 - 0.00308T \qquad (4)$$

Combining equations (3) and (4)

$$\Delta P_b = \beta g H(1.11363 - 0.00308T)(T_{ch} - T_a) \qquad (5)$$

As in equation (5); the buoyancy pressure required to generate air flow through a chimney is directly proportional to the difference between the mean air temperature within the chimney and the ambient air temperature, (Ekechukwu and Norton, 1997).

Within the chimney, pressure drops are due mainly to wall friction. Assuming turbulent flow (with a friction coefficient of 0.03 (Shames, 1976), the pressure drops due to friction loss can be given as (White, 1986),

$$\Delta P_b = 0.03\rho[(v^2 H)/(2D)] \qquad (6)$$

Combining equations (5) and (6),

$$0.03\rho v^2 / 2D = 0.00308g(T_{ch} - T_a) \qquad (7)$$

Thus, air velocity inside the solar chimney is given by;

$$v = 0.453[(Dg/\rho)T_{ch} - T_a]^{0.5} \qquad (8)$$

Equation (8) can be written as;

$$v = f^*(T_{ch} - T_a)^{0.5} \qquad (9)$$

Equation (9) was derived without taking into account the additional buoyancy arising from the increased humidity of the air stream from the medicinal plants being dried. To include this would require the amount of moisture added to the air stream. An assumed value for this would reduce the generality of the analysis. The effect of neglecting moisture gain to the air stream is to give a different value for "f^*" in equation (9), the functional relationship between v and $T_{ch} - T_a$ remains unchanged (Ekechukwu and Norton, 1993).

This study aims to investigate the profits of using the solar chimney with the unglazed perforated passive solar dryer to cut down the energy demand for the medicinal plants drying. A comparison between medicinal plants drying in the unglazed transpired passive dryer with the active system was achieved using the common traditional drying methods. Henna medicinal plants were involved in this study to achieve the quality determination.

MATERIALS AND METHODS

Investigations were carried out to study the effect of augmented solar chimney with the unglazed perforated passive solar dryers. Shaded drying house (traditional drying methods) was used to relate the passive to the active drying processes which was involved in the previous study Hassanain, (2005). Henna leaves was dried in this study as medicinal plant.

Materials preparation:

Henna the Egyptian Privet (*Lowsonia inermis L.*) was dried in the different drying techniques within the period from 5-5-2008 to 2-6-2008. Henna Leaves were selected among the medicinal plants in this study due to the ability of Lowsone components determination instead of depending on the human being sensation determination tests of drying quality; which was given as in the previous investigation. Five kg of Henna leaves were prepared and distributed on the dryer shelves as it is given in the previous work (Hassanain, 2005).

Drying methods involved in the study

To achieve the study goals, toward investigating the effect of using the solar chimney for the unglazed perforated passive solar dryer for the medicinal plants; a shaded drying house (SDH) was considered to compare and relate the effect of both the unglazed perforated passive solar dryer (UPPSD) and unglazed transpired active solar dryer (UTASD) in enhancing the drying quality and cut down the drying operating cost:

Unglazed Perforated Passive Solar Dryer, (UPPSD)

The UPPSD has the same dimensions and materials used for manufacturing the active system. Modifications were carried out on the active solar drying in term of using solar chimney instead of using air blowing in the UTASD. Black PVC Chimney of 3mm wall thickness, 127 mm diameters, 4mm and 4m height from the top of the dryer was mounted (4.75m from the ground base). Also, a transparent acrylic of 4mm thick and dimensions of 15cm wide by 40cm high was fitted and it was sealed on the back dryer door, it was used as a hatch for visualizing the drying process and smoke test. Figure (1) shows the UPPSD.

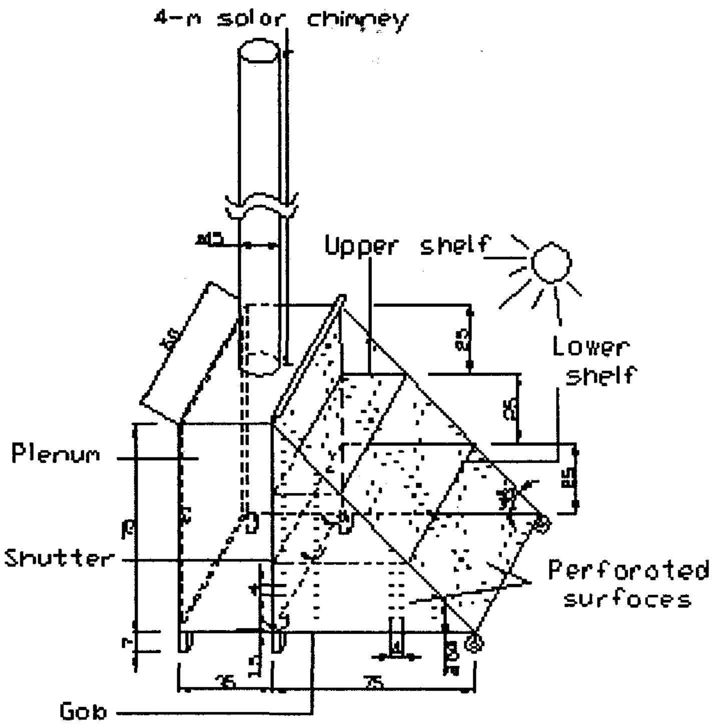

Figure (1). The unglazed perforated passive solar dryer (UPPSD).

Unglazed transpired active solar dryer (UTASD)

The active unglazed transpired solar dryer of Hassanain (2005) is shown in figure (2). Suction airflow rate of $0.06m^3s^{-1}$ was used within this research (the highest available suction airflow) obtained from a suction fan model WME-150, of 150mm diameter, 220-240 Volt (50 hertz), 0.13 Ampere, Chinese made. Taking into the consideration the drying air temperatures increased with the reduction of suction velocity, at the same time high drying air temperatures is not recommended during the medical plants drying. As it affects its quality due to the degradation of the chemical and oils components.

Shaded Drying House (SDH)

Solar drying house (SDH) manufactured from palm-tree leave ribs of thickness 13 to 15 mm and with the given dimensions that are shown in figure (3). Dimensions of the shaded drying house were 0.65 m length x 0.45m, width x 0.95m, height. Cardboard was used to form the drier roof; it was inclined 45° of two directions. This tilt enabled stains and dust to slide away from the product under drying. The upper shelf of the drier was located at 0.28m underneath the span roof, while the lower one was at 0.42m above the ground. Screen mesh covered these shelves. From the previous study results which was carried out on the medicinal plants drying in the open air under the direct-sunrays: This drying method was omitted from this investigation due to the prevailing disadvantages revealed on the dried medicinal plants. As the conventional drying in shaded area represented as solar drying house method (SDH) was used to compare both of the passive and active drying processes.

Measurements:

Incident solar radiation on the different dryer surfaces:

Mono Crestline solar cell with dimensions of 75 mm by 75 mm voltage of 0.5 volt and current of 800 m Ampere was used to determine the global radiation. The short circuit readings that were obtained from the cell were calibrated against Aapply Pyranometer at the Faculty of Engineering, Mansura University according to Mujahed and Almoud, (1988) and Duffie and Beckman, (1991). Formula resulted from calibration against apply Pyranometer was used to determine the incident solar radiation.

Measurements were carried out at two hours later than the sunrise of each day to determine the incident solar radiation on the east surface of the dryer, the cell was made parallel to measure the incident solar radiation on the surface, the same was made with the south tilted surface horizontal and the western surface. The incident radiation on the different sides was predicted using a computation model derived by El-sayed *et. al.* (2005).

Wind speed

Due to the effect of wind speed on the convection heat loss from the unglazed transpired dryer surfaces it was measured using a TESTO 405-V1 Hot Wire Anemometer. Meanwhile, wind direction was determined using a wind vane instrument within this study. To obtain average wind speed within two-hour intervals from the sunrise to the sunset, 60 readings were taken and varied..

Air velocity:

Chimney and dryer air velocity were also measured by a TESTO-405-V1 hot wire anemometer. Air velocity was measured at the chimney central axis.

Temperatures:

Temperatures of the ambient air, chimney flowing air, dryer perforated surface, and the drying air, were measured by Ama-Digit Ad 15^{th}, electronic thermometer type which had been calibrated before against a calibrated mercury, -10:100°C scale thermometer with standard deviation between the thermometers reading of ±0.25°C.

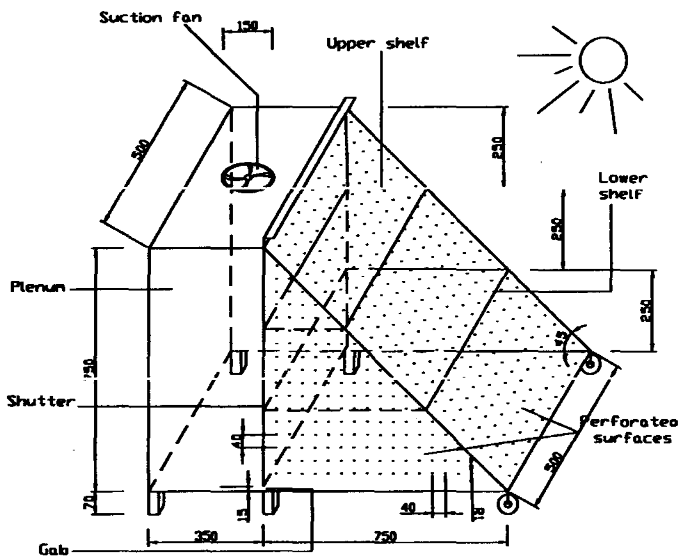

Figure (2). The unglazed transpired solar dryer of Hassanain (2005).

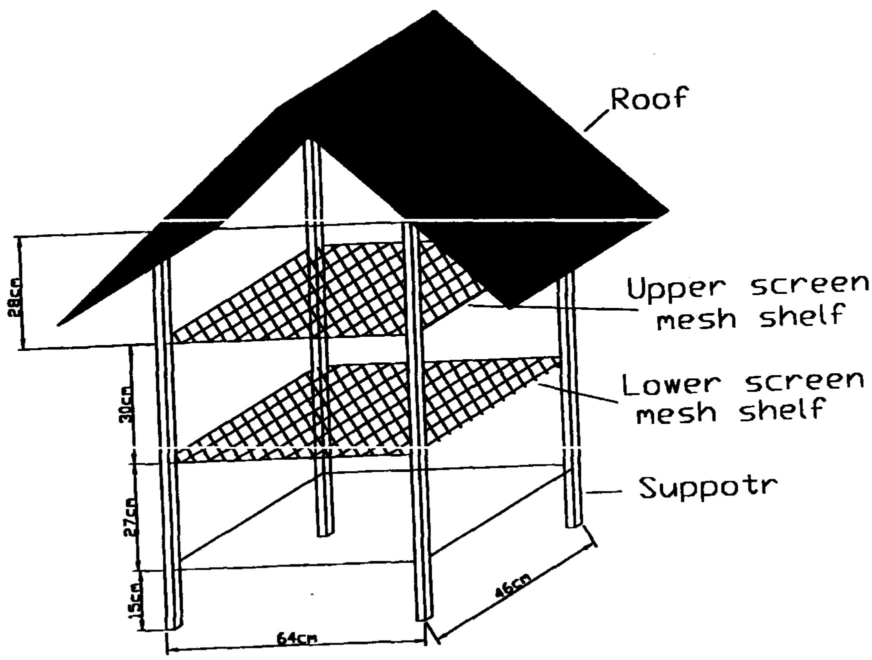

Figure (3). Shaded drying house (SDH).

Three points were selected to carry out air temperature measurements. These points were distributed at the center of the vertical axis of the drying compartment at 15, 41 and 57cm from the dryer top horizontal surface and at 15cm depth from the western surface. The three points were dividing the dryer compartment to three levels at the top, middle and bottom. Air temperature measurements were taken and averaged for each point. Meanwhile, five sensors were used to vary the perforated surfaces temperatures of the east, and west sides. The south oriented slope surface was divided into equal dimensional three levels top, middle and bottom. Several sensors were used to determine each part which was averaged each measurement.

Relative humidity:

The relative humidity for the ambient air and the exit air from the dryer were measured by the use of a dry and wet bulb psychrometer which was calibrated previously against mercury thermometer. Using a digital psychrometric chart based on Computer Aided Thermodynamic Tables 2, CATT2 (Sonntag and Borgnakke, 1988), the relative humidity was determined from the resulted data of the dry and wet bulb temperatures.

Visualization of the smoke test:

Air movement due to the chimney effect with the suitable holes diameter was visualized using smoke test. Also, it aims to verify the measured temperatures of the drying air, perforated surface which affect the drying process. Smoke was visualized under steady state configurations using a smoke generator. The smoke generator outlet orifice was connected to the back compartment of the UPPSD. The smoke was intermediately pulsed for 30 second, while video camera was used to record the trial; before introducing smoke, the system was allowed to attain steady state.

Determination of the moisture contents and ratio of drying (R.D.) and time:

To determine the samples initial moisture contents, Ohaus electric balance® with one gram accuracy was used to weigh the fresh samples and after 24 hours. The fresh samples were put in an electric oven at 60°C for 24 hours. The initial wet basis moisture content MC (w.b., %) was determined using the following formula where, (m_i) and (m_f) are the fresh and final sample masses respectively:

$$MC(\text{w.b.,\%}) = \frac{m_i - m_f}{m_i} \text{x}100 \qquad (10)$$

Drying box of 7x5x5cm was made from steel mesh to represent henna leaves moisture contents for each drying shelf. These samples were weighted each two hours and using the initial moisture content to relates the moisture contents at time t, MC_t.

Ratio of drying (*RD*) was determined for Henna leaves (medicinal plant) according to Al-Gendy, (1981) as the ratio between the fresh and the dried masses at the final moisture content. Meanwhile, drying time was considered for the isolation period (only daytime from sunrise to sunset) without taking the nighttime into the consideration; for instance, from 0 hour, drying time till 10 hours (first drying day) and from 10 to 20 hours (second drying day), from 20 to 30hours and from 30 to 40 hours. Ratio of MC_t/MC_i, between moisture content at specific time (MC_t) by the initial moisture content (MC_i) was used to compare the dried Henna leaves with different initial moisture contents. As no relevant and available reviews for Henna equilibrium moisture contents which enable the comparison using the moisture ratio (*MR*) given in the form:

$$MR = \frac{MC_t - MC_e}{MC_i - MC_e} \qquad (11)$$

Quality of dried medicinal plants

The quantity of the effective component (Lowsone) in Henna was used to determine the dried medicinal plants quality. Lowsone was determined in henna laves which were extracted and fractionated by the Thin Layer Chromatography (TLC) at the Food Science Department, Faculty of Agriculture, Suez-Canal University according to **Shatta (1987)**.

RESULTS AND DISCUSSIONS

Weather condition within the drying processes:

Weather conditions within the research tasks were measured and averaged. When Henna leaves were under the drying processes in the unglazed active perforated dryer against the SDH (from 5-5-2008 till 11-5-2008), averages of the dry and wet air temperatures of 27.6 and 18.5°C were measured within drying time (37 hours); while, the air relative humidity were averaged as 44.5%. Meanwhile, the unglazed transpired passive perforated solar dryer was investigated against the SDH within the period from 29-5-2008 till 3-6-2008. Averages of 30.2°C for the ambient air temperature, 40.4% relative humidity, ground temperature of 27.5°C and average wind speed of $0.57ms^{-1}$ and average incident solar radiation of $331Wm^{-2}$ on the dryer surfaces.

Table (1) represents data of some measured weather parameters for the 1st drying days. From Table (1), increasing the drying air temperatures above that of the ambient was noticed depends upon the ambient air temperature, the incident solar radiation in Wm^{-2} and the prevailing wind speed in ms^{-1}.

The daily average weather conditions on the 29th, May, 2008 were 29°C ambient air, 39% relative humidity 27.8°C ground temperatures. This was under prevailing wind speed of $0.78ms^{-1}$ average incident solar radiation falls on the drier surfaces represented in Table (2).

Dryer surface and air temperatures for the UPPSD:

Figure (4) illustrates the tilted perforated surface temperatures (facing south direction) were conducted for the UPPSD on the 29^{th} of May 2008. Meanwhile figure (5) represents drying air temperature profile for the same day. Temperature profile giving in figures (4) and (5) are obtained under average dry and wet bulb temperatures of 29°C and 18.3°C (from the sunrise at 4:54 till the sunset at 18:49), and average wind speed of $0.785ms^{-1}$ and under average measured incident radiation on the UPPSD different surfaces presented in table (2). Meanwhile, a presentation for the incident solar energy computed according to El-Sayed *et al.* (2005) is given in figure (6) for the same day.

From figures (4 & 5), air was sucked via the surface perforation led to cool the surface down this beside the variation in the incident solar radiation on the different dryer surfaces. Also, the wind speed effect to sweep the surface temperature in the case of it is less the suction force toward the dryer and the effect of convection heat loss. These resulted higher average air temperature above that for the average of the tilted surface.

Figure (7) and (8) gives the inclined surface temperatures of UTASD and drying air, for the 1st drying day (5, May, 2008). In general drying air temperatures either for the UPPSD or the UTASD did not exceed 50°C; this is the recommended range for the drying air temperature especially for the medicinal plants which have volatile oils as effective components (Abouzeid, 1988) this reflected a higher quality of the product being dried compared with the traditional drying methods.

Under average dry and wet bulb temperatures of 31.4°C and 19.1°C (from the sunrise at 5:08: till the sunset at 18:36), average wind speed of $0.5 ms^{-1}$ and average measured radiation incident on the active dryer surfaces, UTASD presented in table (3) and computed incident solar energy in figure (9) according to El-Sayed *et al.* (2005).

Table (1): Measured weather conditions for 1st drying days.

Time, h	T_a, °C	Rh_a, %	T_s total	T_{dair}	T_{gr}	Av. vw	Dry, °C	Rh_O%
5th May, 2008, the 1st day of Active drying.								
07:00	22.1	46.7	28.4	29.6	20.5	0.2	33.0	23.5
09:00	28.6	34.0	36.2	36.3	25.2	0.3	40.0	21.5
11:00	32.6	28.9	40.0	45.4	31.0	0.8	43.0	24.6
12:00	34.5	22.4	41.5	47.0	33.9	0.3	42.0	23.6
13:00	36.1	25.3	41.8	50.3	37.1	0.3	45.0	20.8
15:00	34.8	28.5	35.3	41.5	33.9	1.1	40.0	23.1
Average	26.9	26.5	37.2	41.7	30.3	0.5	40.5	22.9
SD	6.8	8.1	5.1	7.6	6.2	0.3	3.6	1.4
1st day of Passive drying on 29th May, 2008								
07:00	22.9	77.0	30.8	32.0	22.8	0.18	35	44.8
09:00	25.9	55.6	31.3	36.1	23.3	1.18	39	39.8
11:00	29.6	29.2	37.6	38.9	28.8	1.02	40	33.2
12:00	31.5	25.7	37.4	38.3	27.8	0.78	40	35.0
13:00	31.8	24.7	37.8	42.7	29.1	0	42	29.9
15:00	32.4	19.2	37.1	43.3	35	0.75	42	28.3
Average	29	38.6	35.3	38.5	27.8	0.65	39.7	35.18
SD	±3.8	± 23		± 4.2	± 4.5	± 0.47	± 2.6	± 6.2

Table (2): Measured incident solar radiation in W/m^2 on the passive dryer surfaces with the total solar energy flux on the dyer, Watt (29th May, 2008)

Time,	East	South	Norh	Horizontal.	West	Total
Hours	Wm^{-2}	Wm^{-2}	Wm^{-2}	Wm^{-2}	Wm^{-2}	W
07:00	416.0	59.8	166.2	162.1	54.8	438.9
08:00	622.9	217.6	192.1	353.1	94.9	708.8
09:00	677.3	405.7	165.3	543.5	130.5	870.2
10:00	627.9	585.2	159.8	720.8	159.8	981.5
11:00	515.9	724.8	181.3	857.9	181.3	1046.8
12:00	347.1	812.1	193.6	926.3	193.6	1029.7
13:00	195.9	828.8	195.9	936.9	254.7	993.5
14:00	188.0	772.2	188.0	897.4	446.9	1050.2
15:00	170.6	652.8	170.6	790.0	584.3	1019.8
Average	418.0	562.1	179.2	687.5	233.4	904.4
SD	±183.7	±273.9	±13.6	±274.3	±121.2	±202.2

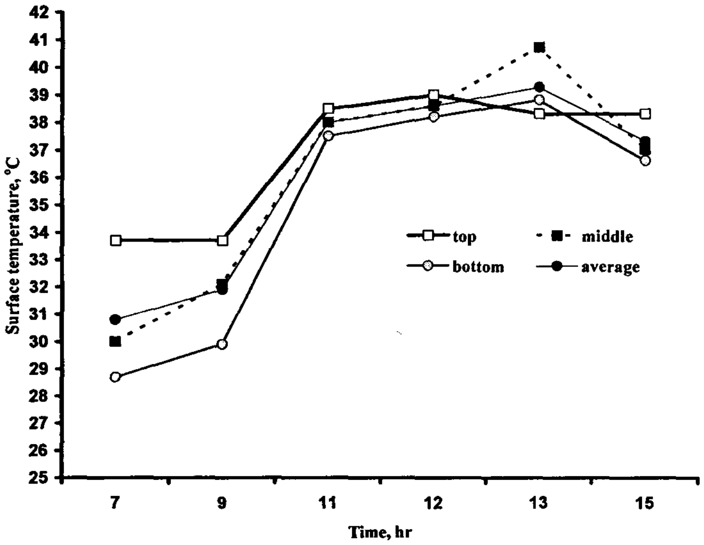

Figure (4): Temperatures against time for the UPPSD surface inclined 45° and facing the south

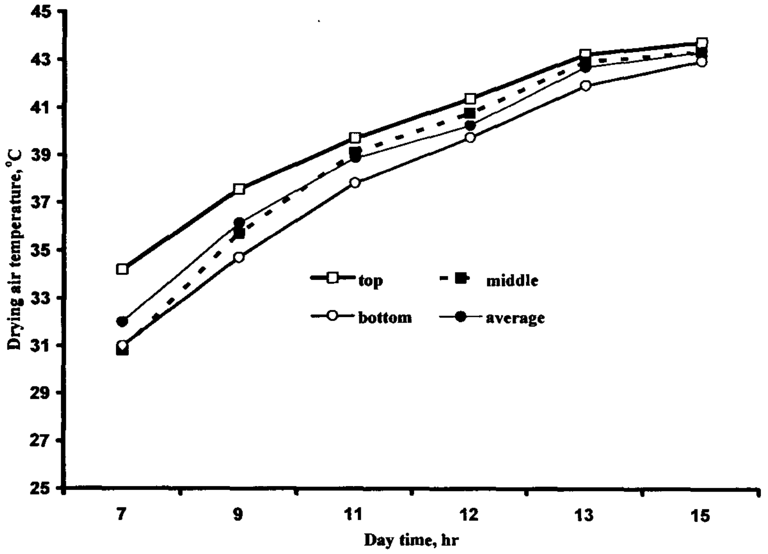

Figure (5): Drying air temperature inside the UPPSD

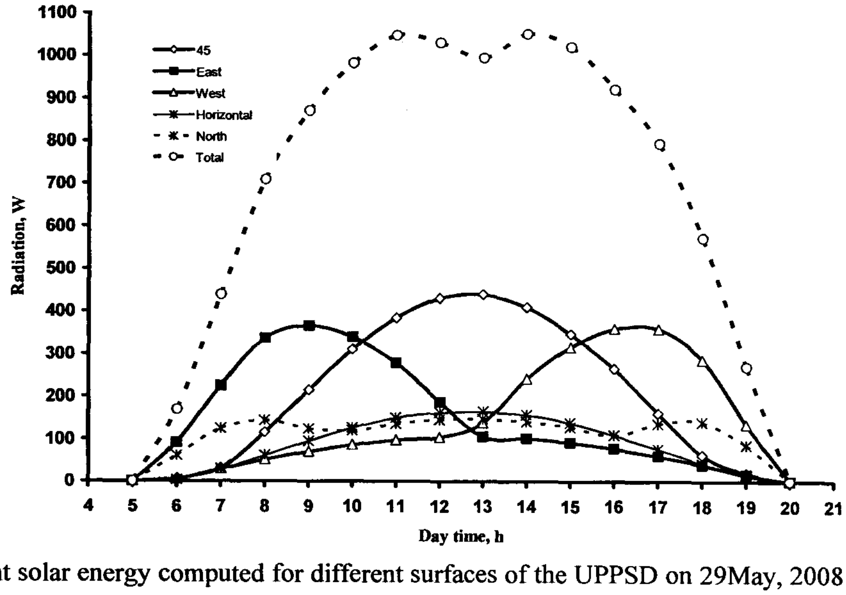

Figure (6): Incident solar energy computed for different surfaces of the UPPSD on 29May, 2008 from the sunrise to sunset

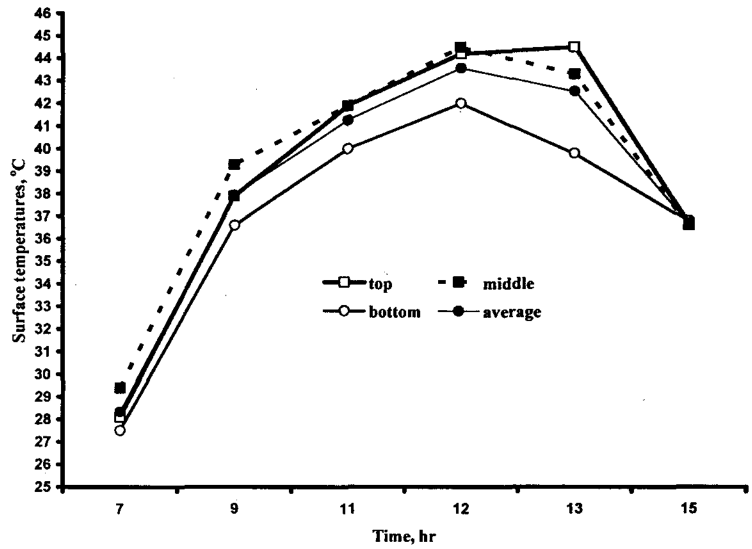

Figure (7): Inclined south facing surface temperature illustrated for the UTASD

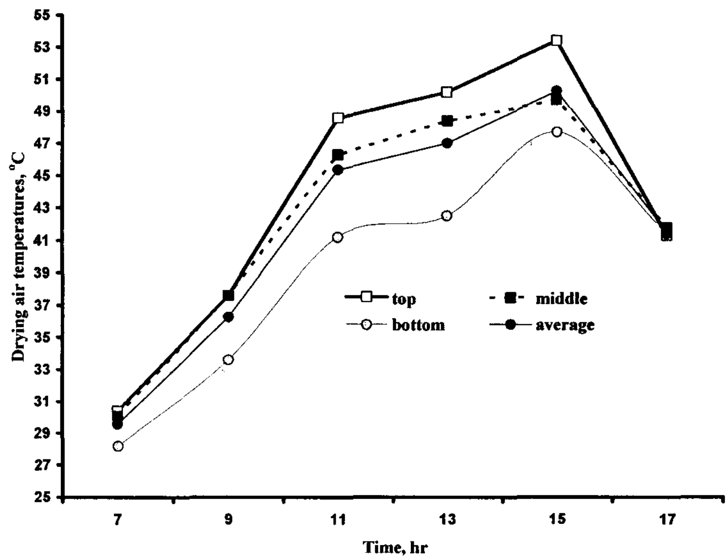

Figure (8): Drying air temperatures inside the UTASD

Table (3): Measured incident radiation (W/m^2) flux on the Active dryer surfaces and total solar energy flux on the dryer, Watt (5th May, 2008).

Time	East	South	Norh	Horizontal	West	Total
Hours	Wm^{-2}	Wm^{-2}	Wm^{-2}	Wm^{-2}	Wm^{-2}	W
07:00	261.5	38.3	91.8	76.0	31.6	260.7
08:00	552.4	164.9	136.3	256.3	75.6	573.6
09:00	677.1	372.6	114.5	454.1	114.5	790.3
10:00	660.5	559.3	147.4	640.8	147.4	955.4
11:00	564.7	724.3	172.5	799.7	172.5	1051.4
12:00	409.7	839.0	188.4	898.1	188.4	1066.2
13:00	200.7	880.2	194.1	928.5	194.1	987.8
14:00	189.1	844.0	189.1	902.0	397.6	1063.9
15:00	173.9	733.6	173.9	808.2	556.5	1055.1
Average	410.0	572.9	156.5	640.4	208.7	867.2
SD	± 208.8	±312.3	±36.2	±310.7	±165.9	±280.6

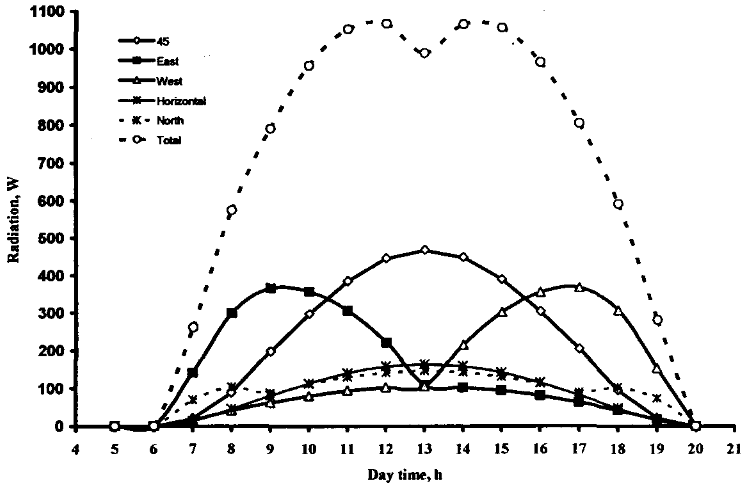

Figure (9): Incident solar energy computed for the different surfaces of the UTASD on the 5th May, 2008 from sunrise to sunset

Smoke visualization test:

The smoke test was carried out under average open environmental weather conditions of 32.7°C ambient air temperature, relative humidity of 44.11%, dryer air temperature of 39.6°C (averages for the three points top medium and bottom of 39.4°C, 40.5°C and 39°C), average ground surface temperatures of 22.8°C, incident radiation on the different sides of 307.1W/m^2 and average wind speed of 0.98ms^{-1}. Smoke visualization revealed that, air movement is faster underneath the shutter according to the theoretical hypothesis of the air flow as shown in plate (1). This reflects the instantaneous reduction temperature of the inclined surface of UPPSD (which is facing the south direction) from the top to the bottom direction (with considering the time lag). This occurred due the air velocity which is resulted from the pressure drop caused due to chimney height which is illustrated in plate (2).

The south facing, inclined surface temperature decreased from the top to the bottom for passive drying as affected by the solar chimney as it is given in figure (4). Also, this was found for the active as in figure (7) due to the suction fan effect. This also affects the interior dryer air temperature with the same temperature trend (from the top to the bottom) for the both dryers within the falling drying period within the 1st drying day; either for the passive dryer, UPPSD as it is shown in figure (5)or the Active dryer as in figure (8)

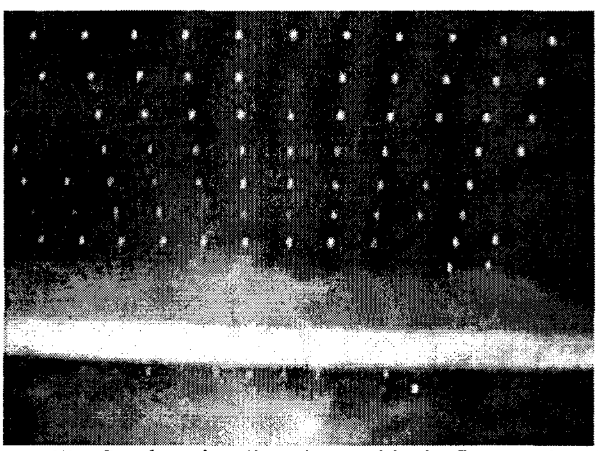

Plate (1): Smoke visualize the rapid air flow under the UPPSD shutter

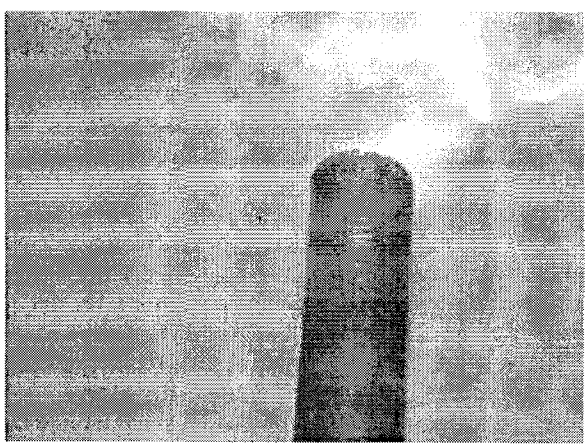

Plate (2): Visualize of air velocity due to chimney height

Determination of the pressure drop caused due to augment solar chimney

The pressure drop caused as a result of attaching the solar chimney to the UPPSD was determined using equations (5). Figure (10) shows the pressure drop in Pascal for the 1st drying day. Daily average pressure drop of 1.538Pascal with average standard deviation of ± 0.226 Pascal was created by solar chimney effect according to equation (5) for the 29th of May from two hours after the sunshine at 4:54 till the 15:00 local time, taken into the consideration, chimney air density was computed using equation (4).

Air velocity factor and Reynolds Number

The daily average value of f^* factor determined from equation (9) within the passive solar chimney effect to enhance the drying of the medicinal plants. It was found to be 0.113 with standard deviation of ±0.0296 (from 4:54 till the sunset at 18:49 of 29th, May, 2008). Presenting the relationship between the measured chimney air velocity and the value of f^* factor with a linear fitting line resulted a linear equation with R^2 of 0.93 it can be written in the form:

$$f^* = 0.304(v) + 0.0011$$

The daily average chimney air velocity it was found as 3.27ms^{-1} with standard deviation of ±0.23 ms^{-1}., according to the formula (9). The daily average of chimney measured air velocity from table (4) was found to be 0.37ms^{-1} ±0.19 ms^{-1} (within the measurements campaign).

Reynolds numbers based on the average chimney air velocity for the UPPSD (with 4m chimney height) is given in table (4). It was lower than that of the active dryer, (turbulent flow with average Reynolds number of 16110). From table (4) daily average of Reynold's Number for the 1st drying day on 29th, May, 2008 was found to be 2967±757 for measured chimney air velocity of 0.37ms^{-1} when the chimney air temperature was 39.7°C±2.8°C (daily average from two hours from the sun rise till 15:00). Chimney air densities in kgm^{-3}, presented in table (4) are computed according to equation (4).

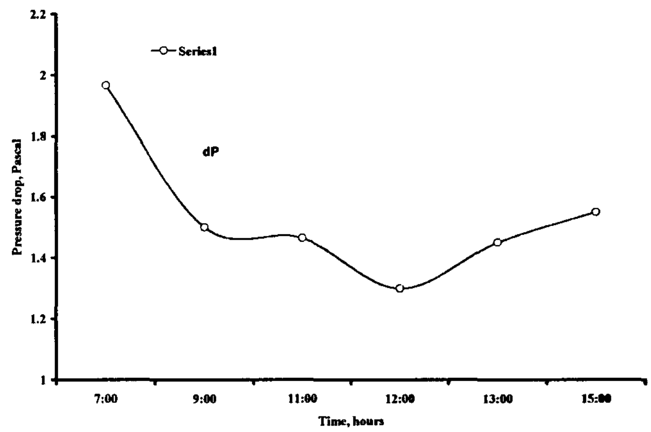

Figure (10): Pressure drop caused by the solar chimney vs time on 29th May 2008

Table (4): Reynolds number of chimney air based on measured velocity

Time	Chimney air velocity, ms^{-1}	Chimney temperature, °C	Chimney air density, kgm^{-3}	Re, based on measured velocity
07:00	0.39	36.6	1.0009	3172
09:00	0.26	36.3	1.0018	2117
11:00	0.54	39.8	0.9910	4349
12:00	0.34	40.5	0.9889	2732
13:00	0.33	41.9	0.9846	2640
15:00	0.35	43.2	0.9806	2789
Average	0.37	39.7	0.991303	2967
SD	±0.19 ms^{-1}	±2.8°C	±0.009 kgm^{-3}	±757

Drying rate and drying ratio (D.R.):

Average moisture contents (wb), % for Henna leaves are given in figure (10A) under the previously mentioned daily average weather conditions for the 1st drying day on 29th May, 2008 for the passive drier, UPPSD and the shaded drying house SDH. Meanwhile, distribution for moisture contents of Henna was determined at the three shelves (lower, medium and the upper) within the first 10 hours versus drying time presented in Figure (10B). Figure (11A) shows moisture contents (w.b., %) versus the drying time in hours for the first drying day of henna leaves drying in the active dryer on the 5th May, 2008 with the distribution shows in Figure (11B). The benefits from using the unglazed transpired solar dryers either the active or passive systems for medical plants above the traditional drying methods are the fast decrease in the moisture content higher quality measured (Lowsone in this case) as it will discuss in the drying quality. Henna leaves was losing it moisture contents faster when it was dried on the lower dryer shelf than the two other shelves. Shelf arrangement among the dryers plays a significant role in speeding up medicinal plants drying. For the passive solar dryer the fast reduction in the leaves moisture contents as it is seen in Figures 10B can be arranged as the lower shelf then the medium then upper shelf. This refers to the drying air temperature and air velocity due to the chimney effect. The same effect is obvious in Figure (11B) due to the air suction fan effect for the active dryer.

Average of the percentage of moisture content per minute for henna, are presented in pairs of comparison (Active vs. SDH) and (passive, UPPSD vs. SDH) table (5) in (w.b.) % per minute. This values were computed

$$\text{as} \sum_{t10}^{t0} MC_t \,/(2\text{x}60),$$

taking for two hours interval and (t) is the drying time from 0 till 10 hours.

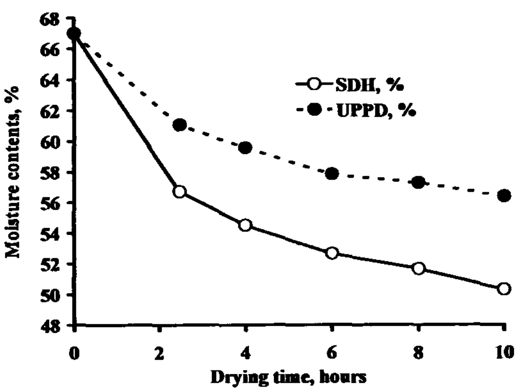

Figure (10*A*): Moisture content of Henna dried within the 1st day in the passive dryer (UPPSD)

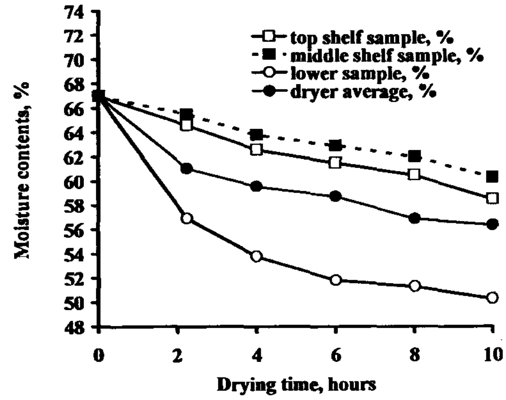

Figure (10*B*): Distribution for shelves moisture contents as a result of drying air temperature and air velocity due to chimney effect in the UPPSD for the 1st drying day.

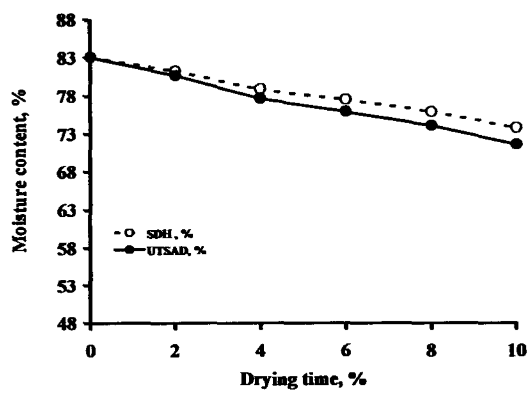

Figure (11*A*): Moisture contents of Henna versus drying time in Active dryer for the 1st day.

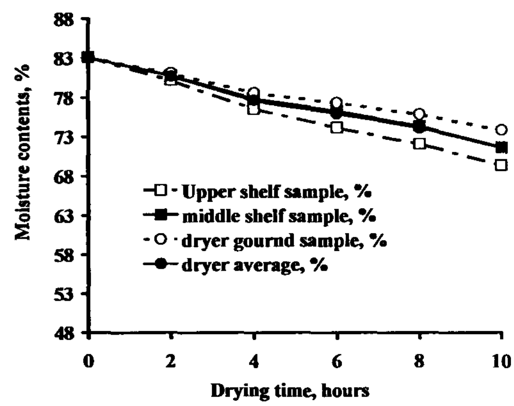

Figure (11*B*): Distribution for shelves moisture contents as a result of drying air temperature and suction air velocity in the Active dryer for the 1st drying day.

Table (5): Henna average drying rate in (w.b., %)/minute for different drying methods for the 1st day.

Active vs. SDH		Passive, UPPSD vs. SDH	
Active	**SDH**	**UPPSD**	**SDH**
0.0192	0.0156	0.0177	0.0278

Ratios of Drying *(RD)* were determined till reaching the medicinal plant to the end of the investigation at the equilibrium with the surrounding weather conditions given previously: For average initial moisture content (MC_i) of 64.7% till 44.8 the final (MC_f) moisture contents, the drying ratio was calculated to be in average of 1.6:1 according to previous given equation.

Ratio of MC_f/MC_i, within the drying time for the passive, UPPSD and active dryers are shown in Figures (12) and (13) respectively. Meanwhile it is shown in Figure (14) to compare both of active and passive dryers.

Lawsone determination in Henna as an indicator for quality of medicinal plants drying techniques:

The qualities of the Henna leaves as medicinal plant were determined as the percent of Lowson and presented in Table (6). Average Lowsone Percentage at moisture content of 41.6% and average PH 4.44 was found as 1.1 and 1.1% i.e. no difference in the Lowsone content for the drying henna in the Active and Passive UPPSD, while it was found as 1.09% (average of two trials) when it was dried in the shaded drying house SDH.

Table (6): Percent of the average Lowsone in Henna for MC 41.6% and pH 4.44.

Dryer type	**Active drying**	**SDH av.**	**Passive, UPPSD**
Lowsone, %	1.1	1.09	1.10

Cost per the unit of dried Henna leaves

To discuss the effect of Augmented solar chimney to the unglazed perforated passive solar dryer on the total cost the electric power consumed by the suction fan of the active dryer was determined. Fixed and operating costs, were considered when the Cost per unit of the final dried product was addressed. Maintenance was taken as 3% from the cost of the newly built solar drying system. Capital costs were determined according to 2008 prices as L.E.350 (Egyptian pounds) for the active dryer, L.E. 50 for the shaded drying house and L.E. 300 for the capital cost of the UPPSD. The final dried medicinal plants product prices were also determined according to 2008 prices as 10 L.E./kg Henna. The study found that drying one kg cost 1.83. 1.60 and 1.74 L.E. in the Active, shaded drying house and passive drying UPPSD respectively. Drying cost did not address the quality of the dried medicinal plants on the comparison between the three drying methods.

The consumed electrical energy by the suction fan of the Active solar dryer (determined just for 26 hours) as 0.81 kW.h as it cost 0.1 L.E.

CONCLUSIONS

The study conducted to the following conclusions:

- Visualizing the smoke test and the measurements campaigns revealed that, solar chimney affected temperatures of the inclined south surface also the drying air which were found increases from the dryer top to the bottom. Due to the differences of drying air temperature caused by the chimney effect it resulted in fast drying from the bottom to the top of the dryer.
- Due to 4m chimney height augmented to the unglazed perforated passive solar dryer, it caused daily average pressure drop of 1.538 Pascal with standard deviation of ±0.226 Pascal.
- Daily average Reynolds number of 2967 was determined for average measured chimney air velocity of $0.37 ms^{-1}$ when the chimney air temperature was of 39.7°C.
- Using the passive design with solar chimney for drying Henna leaves affect the cost of the unit drying which was found as 1.74L.E compared 1.83L.E with that dried in the active drier.

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