EXPERIMENTAL STUDY ON SOLAR DISTILLATION SYSTEM FOR OIL EXTRACTION FROM EUCALYPTUS PLANT LEAVES

by

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Most of the industrial process requires a temperature level below 250 °C which is easily achievable using solar energy. Pakistan is fortunate enough to have long sunlight hours and high intensity of solar insolation. The mean total irradiation falling on a horizontal plane is about 200-250 W/m^2 per day. This precious source of natural energy has tremendous potential in the agro-based industry like the distillation of medicinal plants. The main objective of this study was to conduct a quantitative and qualitative analyses of solar distilled oil of the medicinal plant. Solar distillation systems had been installed at Agricultural Engineering Workshop, Faculty of Agricultural Engineering, and Technology and Rosa Lab, Institute of Horticultural Sciences, University of Agriculture, Faisalabad. This distillation system was designed according to the latitude of Faisalabad. This system comprised of primary reflector, secondary reflector, condenser, and Florentine flask. In this study Eucalyptus Camaldulensis and Eucalyptus Citriodora, essential oils were distilled by solar distillation system and by a conventional distillation system for comparing the results. Gas chromatography-mass spectrometry analysis of Eucalyptus Camaldulensis and Eucalyptus Citriodora essential oils were carried out at National Institute of Biotechnology and Genetic Engineering, Faisalabad. The results of quantitative and qualitative analyses of essential oils showed that the quantity and the quality of essential oils of same species of eucalyptus, distilled by solar distillation system and conventional controlled distillation system were same. So, it was concluded that the quality and quantity of essential oils of same species do not differ significantly either distilled by solar distillation system or by conventional controlled distillation system.

Key words: *distillation, eucalyptus oils, solar energy, gas chromatography, qualitative and quantitative analysis*

Introduction

Solar energy is clean, free, and the most abundant source of renewable energy. The Sun has been used as a source of energy in different ways for many centuries. Pakistan being in the sun-drenched strap is fortunate to have long sunlight hours and high intensity of radiation. The solar energy amounts to about 1500-3000 sunlight hours and 1.9-2.3 MWh/m^2 per year

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[1, 2]. In most industries, all the processes make use of heat lower than 180 °C. This temperature range can be achieved by using different tube collectors and solar concentrators [3, 4]. Most of the industrial processes including pasteurization, extraction, sterilization, drying, hydrolyzing, distillation, evaporation, washing, and polymerization require a medium temperature range (60-280 °C) [5-7]. Solar energy is being used to perform the aforementioned process, as a study was conducted to modify the distillation system as an active one and it was verified and recommended that for efficient and economic production of potable water in a sustainable manner, active solar distillation technology should be followed [8]. A study was carried out to review of solar desalting units with evacuated tube collectors (ETC) and this showed that the use of ETC are not popular in solar desalting units [9]. The performance of a passive ETC solar still was analyzed based on energy matrices and enviro-economic parameters [10]. Different passive solar desalting designs was studied to understand better, efficient, and productive performing system along with different novel solar desalting systems [11]. Nowadays, human beings are utilizing solar energy for cooking and steam generation purposes, however the utilization of solar energy for the extraction of essential oils from medicinal and aromatic plants is an innovative application of solar energy. Distillation is a process of extracting clean and refined oil from the plant materials by evaporating the volatile essence [12-15]. Essential oils are the steam or water distilled volatile products of the plant materials and a complicated mixture of chemical compounds which are responsible for its definite characteristics. Many experimental studies have been conducted on the extraction of essential oils from medicinal and aromatic plants. The essential oil of the Eucalyptus is extracted from different parts of the tree which depends upon the species but the oils which are extracted from its leaves are most valuable. The essential oil present in the fresh weight of leaves of different species is up to 0.1-7% [16-18]. As per estimations about 4000 tons of Eucalyptus is being produced in the world and about 60-70% of total consumption takes place in the medicinal industry. Eucalyptus oil aids in curing different diseases such as cold, chest pain, influenza, and skin rashes. Oil vapors of Eucalyptus are inhaled to oppose inflammation [19-23]. A solar-based distillation system serves the purpose of effective utilization of heat radiations and is considered energy efficient. As gas prices are higher especially in Pakistan, the conventional distillation system is becoming expensive in terms of cost of production. On the contrary, a solar-based distillation system turns out to be cost-effective, energy optimal, and coherent [24-26]. This study aimed to develop an on-farm solar distillation system to process the fresh supply of different medicinal and aromatic plants with solar energy. A simple distillation unit consists of four parts: furnace (heat source), distillation still, condenser, and oil separator. Three types of distillation are in practice, these are: *water distillation* (distillation with water), *water and steam distillation*, and *steam distillation* (distillation with steam). The yield, composition, quality, and commercial value of the essential oils are generally affected by the type and efficiency of the distillation unit, as well as age of the harvested plant material and ecological conditions where plant material is cultivated or wild harvested [27, 28]. A solar distillation system has been adopted to utilize the solar energy for the distillation of essential oil from medicinal and aromatic plants. The solar distillation systems have been installed at Agricultural Engineering Workshop, Faculty of Agricultural Engineering and Technology and Rosa Lab, Institute of Horticultural Sciences, University of Agriculture Faisalabad. This system had the following parts primary reflector, secondary reflector, condenser, oil separator or Florentine flask. Fixed focus Scheffler reflector was used as a primary reflector in this solar distillation system. Area of this reflector was 10 m^2. The reflecting surface of this reflector was made of high reflective mirror. This reflector concentrates all the radiationward a fixed point after striking its reflecting area. A

secondary reflector which was made of high reflective aluminum profile, was placed at the focal point of primary reflector to converge all the radiation on the bottom of still. Secondary reflector was kept at distance of 4000 mm from the foundation of stand. The still which was used for the solar distillation system was like the conventional still. The difference between conventional distillation system and solar distillation system was the energy source. As the conventional distillation system had a burner and natural gas was used for heating purposes while in solar distillation system solar energy was used for heating purpose. The present study focuses on qualitative and quantitative analyses of essential oils of Eucalyptus, distilled using solar and conventional distillation systems. Gas chromatography mass spectrometry analysis were also performed on eucalyptus oils [29-31].

Materials and methods

Two solar distillation systems were installed each at the Agricultural Engineering Workshop, Faculty of Agricultural Engineering and Technology and Rosa Lab, Institute of Horticultural Sciences, University of Agriculture Faisalabad. The component of the solar distillation system were: a primary reflector, pressure gauges, top covers of distillation still, distillation still, water level indicator, an outlet for water, secondary reflector, an outlet for hydrosol from florentine flask, florentine flask, water inlet toward condenser, condenser, and hot water outlet from condenser. The total available energy for the distillation process depends upon beam radiations, reflectivity of glass mirror and thermal efficiency of the system [32].

Figure 1 shows the solar distillation system. Fixed focus Scheffler reflector (10 m^2 area) was used as a primary reflector in this system. Reflecting surface of the reflector was made of

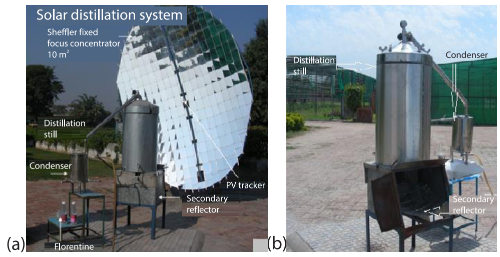

Figure 1. Pictorial representation of solar distillation system; (a) front view and (b) back view of the secondary reflector with distillation still

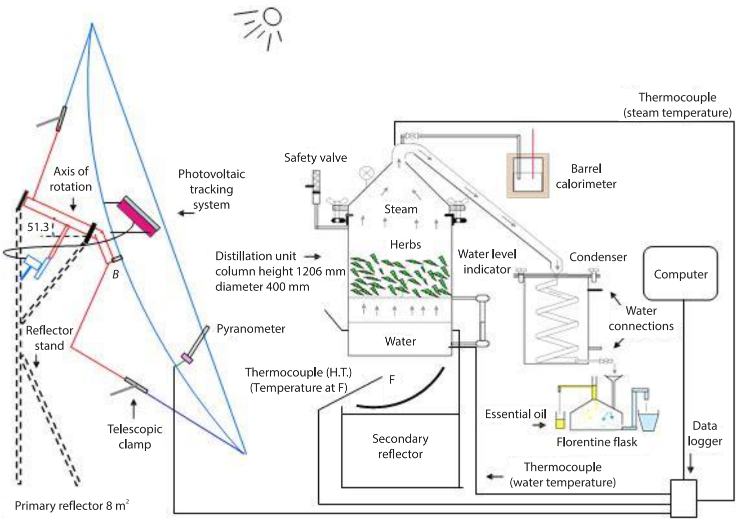

Figure 2. Schematic diagram of solar distillation system reproduce from the source [32]

a high reflective mirror. A secondary reflector was made of a highly reflective aluminum profile at focal point of the primary reflector to converge all radiations on the bottom of the still. Figure 2 shows the schematic diagram of the solar distillation system. Quantitative and qualitative analyses of solar distilled and conventionally natural gas-fired distilled essential oils of *Eucalyptus camaldulensis* and *Eucalyptus citriodora* were carried out to compare the quantity and quality of solar distilled essential oils with conventionally distilled oils. Five-kilogram fresh leaves of both Eucalyptus species were subjected to water cum steam distillation for 6 hours and 2.5 hours using a solar distillation system and conventional controlled distillation system, respectively. Obtained oils were dried over anhydrous sodium sulphate (Na_2SO_4). After adding sodium sulphate, oil samples were filtered using a filter paper. These samples were centrifuged at 25 °C for 15 minutes at 1500 rpm and centrifuged oil samples were stored at 4 °C in the refrigerator until it was analyzed gas chromatography-mass spectrometry [33].

Solar distillation system

Description of primary and secondary reflectors for solar distillation system

Fixed focus Scheffler concentrator worked as a primary reflector. Major components of this reflector were the elliptical reflector frame, tracking channel, rotating support, reflector stand, a mirror as reflecting material, and daily and seasonal tracking devices. A primary reflector was a lateral part of a paraboloid. Several crossbars were used to form a required section. The U-profiles of aluminum were placed on these crossbars to support the small pieces of high reflective mirror. Size of mirror pieces was 226 mm × 152 mm.

The journal bearings assembly was welded with reflector frame along a line parallel to polar axis by setting it in north-south direction and inclination angle (31.25°) with the horizontal. Axis of rotation (steel pipe) of reflector assembly was inserted into journal's bearings. A PV tracking device was used to rotate primary reflector by chain sprocket mechanism for daily tracking, with an angular velocity of one revolution per day to counterbalance earth rotation. Seasonal tracking devices were made of telescopic clamps mechanism and have been rotated manually at half angle of solar declination. It induces the desired shape of the reflector paraboloid to get fixed focus throughout the year.

A secondary reflector (designed according to latitude of Faisalabad city) was used to further reflect radiations on the bottom of distillation still. Heat energy was supplied from bottom side of still. This design was easy to operate and handle. The beam radiations were equally scattered on the bottom of the distillation still and solar thermal energy was best utilized like a conventional furnace under the still. The geometric concentration ratio of the Scheffler reflector was 100. The secondary reflector was designed to converge all the radiations to the bottom of the distillation still (400 mm diameter). High reflective aluminum foils, resting on two laterals and one central support, were used as a secondary reflector. The secondary reflector frame was made of square pipes. Supports of the secondary reflector were riveted to the frame of the secondary reflector. Six aluminum foils (curved at 560 mm radii) were used as a secondary reflector. Curvature to aluminum foils was given by using flat bars called stiffener (curved at 560 mm radii) of size 25 mm width, 6 mm thickness, and 620 mm length.

Design of still for solar distillation system

The still unit consists of condenser, oil separator/Florentine vessel, and thermal insulations. A stainless-steel coil-type condenser was used which aided in equalizing temperature of resultant mixture with ambient temperature (35-45 °C). Function of an oil separator or Florentine vessel is to separate the oil from the water phase and was designed to accommodate volatile material (essential oil). The essential oils are sparingly soluble in water, and this property makes it possible to affect the separation from the aqueous phase. The Florentine vessels were designed to enable the continuous removal of the water phase during distillation. Loss of heat from the still is accompanied by a corresponding condensation within the still, which later re-boils. This could have detrimental effect on product quality [24, 34, 35]. Thermal insulation is therefore, an important requirement. Rockwool was used to insulate the distillation still and the insulation was held with a wire binding. The distillation still comprised of the vertical shell (900 mm height) and top cover. The upper 750 mm of the vertical shell of the distillation still was insulated while 150 mm bottom lateral part was not insulated as this portion of the still exposed to the solar radiations and painted black with solar mat. Cylindrical still body mounted vertically has more practical usage. The judgment of the appropriate size is related to the quantity of the plant material available for distillation per harvest, availability of water and steam, energy sources and availability, labor availability, transport and storage facilities for the raw material and oil [34, 37]. Still body was equipped with a perforated grid near the bottom of the body itself. The loaded charge rests on the grid while performing water and steam distillation. In the experiments water-cum-steam distillation method was used, the compartment below the grid serves as the reservoir for the boiling which generates the steam. In a cylindrical still, the space between the water and the herb supporting grid should have a depth to one-fifth of the still's diameter. This leaves room for an efficient scheme of baffles [32]. The present model was designed for water cum steam distillation, the still body rests on a secondary reflector which heats the bottom of the still indirectly by secondary reflected beam. The distillation still was fabricated with a food grade stainless steel vessel having 1210 mm column height, 400 mm diameter and 2 mm thickness. Still vessel was fabricated as pressure-tight and all welds relevant to this requirement were made continuous and of the required quality. The safety mountings and fittings like a safety valve, pressure gauge, and water level indicator were fitted on still. A drain line connection was provided at the bottom to drain the water of the used charge. The still was tested to check against any leakage by installing a vertical pipe element to the vapor outlet connection plugging the drain line and filling it with water up to the top of the vertical pipe element. The shape of the top cover was conical, and it was made of 2 mm stainless plate and its lateral part was 4 mm thick to avoid any distortion during welding. Three I-bolts were used for quick opening and closing of the conical top cover during distillation experiments.

Fabrication of condenser

The main function of the condensing system is to convert the vapor mixture of the steam and essential oil which emerges from the still body outlet, swiftly into the liquid phase. This function involves the removal of the heat from the vapor phase to render it into a liquid phase and to bring the resultant mixture of aqueous and oil phases to near ambient temperature, about 35-45 °C. In general practice within the essential oil industry, there is a variety of different types of condensers. The most two popular designs are known as the coil-in-water type and shell-and-tube type. The coil type is more prevalent in developing countries. The reason is based both on the economy as well as on grounds of ease of fabrication in circumstances where good workshop facilities are not available. The condenser was provided with a steel coil, a cold-water inlet connection, and a warm water outlet connection and acts as a counter-current flow heat exchanger. The whole coil was immersed in the static water tank. The complete condenser unit was also made of stainless-steel material along with the vapor outlet pipe from still to the condenser. The shell and core of the condenser were fabricated for watertight. The shell was leak tested by filling it with water and core by immersing in water and checking for air bubbles. The coil was a stainless-steel tube bent on a tube bending machine of the correct diameter to produce a coil of the specified diameter and pitch. The diameter of the coil was 10 mm, and the pitch was 25 mm. The diameter, height, and wall thickness of the shell are 250 mm, 350 mm, and 3 mm, respectively. The coil unit was placed loose inside the shell. Cooling water inlet and outlet connections were provided from the bottom and top sides of the condenser shell, respectively for efficient condensation of the steam inside the coil.

Florentine vessel or oil separator

The condensate that emerges from steam distillation (that is the distillate), is a mixture of essential oil and water. The essential oil may eventually settle as an upper layer (lighter than water) or as a lower layer (heavier than water). The function of an oil separator or Florentine vessel is to separate the oil from the water. The essential oils are sparingly soluble in water, and this is the property that makes the separation of essential oil possible. The Florentine vessels were designed to enable the continuous removal of the water phase during distillation.

Operational procedure for the solar distillation system

Experimental work started with still covers opening before loading the still with plant materials. The cover of the still was handled manually. The I-bolts of the cover were loosened and swung out of the way. Plant materials were charged in the still and re-placed the top cover after checking its seal. Plant materials were placed in water for hydro distillation of essential oils and plant materials were placed on the perforated grid for water cum steam distillation. Water was filled up to 120 mm from the bottom of the still which is equivalent to 15 kg. The focus of the primary reflector was adjusted before the start of the experiment and telescopic clamps bolts were opened to free the primary reflector along the seasonal tracking axis. The presence of a clutch plate makes the rotation of the primary reflector forever flexible along the daily tracking axis. In this way, the reflector can also be rotated along both axes of tracking by holding telescopic clamps either from the top side or bottom side to set the focus accurately. The finest focus is set by visualizing the illuminating beam of solar radiation at the focus. If the focus is a little bit higher than the designed focus point, then the top side of the reflector is tightened by fixing the downward side and vice versa.

Figure 3. Pictorial representation of the controlled distillation system

Controlled distillation system

This distillation system has four major parts as distillation still, furnace, condenser, and Florentine flask. A basket was provided in the still to facilitate the handling of plant materials and there was permission in this still to perform hydro distillation and water cum steam distillation. For performing water or hydro distillation, plant materials were dipped in water and for water-cum-steam distillation plant materials were kept in a basket. Figure 3 shows the controlled distillation system. Technical specifications of this distillation system were the internal diameter of controlled distillation still was 406.00 mm, depth of controlled distillation still was 793.00 mm, Distillation stills wall thickness was 2.00 mm, the internal diameter of the basket was 401.00 mm, the wall thickness of the basket was 2.00 mm, the depth of the basket was 400.00 mm, and the thermal insulation thickness was 25.4 mm.

Plant materials collection and preparation for the distillation process

Fresh leaves of *Eucalyptus camaldulensis* and *Eucalyptus citriodora* were collected early in the morning from the Eucalyptus trees which were grown at the University of Agriculture, Faisalabad. The experiments were performed in the month of June. In Faisalabad, Pakistan June is the hottest month of summer season. The average low and high temperature during the month of June are 25-30 °C and 45-48 °C, respectively. The ambient temperature was 28 °C on the day of the experiment. Leaves of both species of Eucalyptus were examined by a taxonomist, Department of Botany, University of Agriculture Faisalabad for investigation of their species. Five-kilogram fresh leaves of both Eucalyptus species were subjected to water cum steam distillation for 6 hours and 2.5 hours using a solar distillation system and conventional distillation unit, respectively. Obtained oils were dried over anhydrous Na_2SO_4 [31]. After adding sodium sulphate, oil samples were filtered using a filter paper. These samples were centrifuged at 25 °C for 15 minutes at 1500 rpm and centrifuged oil samples were stored at 4 °C in the refrigerator until it was analyzed by gas chromatography and gas chromatography-mass spectrometry analysis [32]. A Sigma 2K15C Laboratory centrifuge was used to centrifuge the oils samples, which is available at the Department of Parasitology, Faculty of Veterinary Sciences, University of Agriculture Faisalabad. The maximum rotor speed of Sigma 2K15C is 14000 rpm.

Gas chromatography-mass spectrometry analyses

Gas chromatography-mass spectrometry (GC-MS) analyses were carried out for the Qualitative investigation of solar and gas-fired distilled essential oils. The GC-MS analysis of Eucalyptus essential oils was performed using a Polaris Q ion trap mass spectrometer equipped with Trace GC Ultra. These analyses were carried out at Health Biotechnology Division, National Institute of Biotechnology and Genetic Engineering, Faisalabad. The Polaris Q with Trace GC Ultra with a capillary column of length and diameter 30 m and 0.25 mm, respectively was used for GC-MS analysis. Other parameters were samples size of one microliter, carrier gas – helium (He) at flow rate of 1.0 mL per minute, temperature of injector port at 200 °C, initial temperature of column at 120 °C, final temperature of column at 250 °C, initial hold up time 1 minute, final hold up time 5 minutes, sample run time 25 minutes, and rate of Ram was 10 °C per minute.

Statistical analysis

The experiments were laid out according to completely randomized design with two treatments and eight replications. The data obtained was subjected to statistical analysis for the significance of mean values of both treatments and treatments means were compared by using t-test at 5% probability. The following equations were used to perform the statistical analysis. For mean yield of essential oil:

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{1}$$

where $\overline{x}$ is the mean of all observation, x_i – the value in one observation, and n – the number of observations. For variance:

$$S^2 = \frac{\sum_{i=1}^{n}\left(x_i + \overline{x}\right)^2}{n-1} \tag{2}$$

where S_2 is the sample variance, x_i – the value in one observation, $\overline{x}$ – the mean of all observations and n – the number of observations. For standard deviation:

$$S = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i + \overline{x}\right)^2}{n-1}} \tag{3}$$

where S is the standard deviation, x_i – the value in one observation, $\overline{x}$ – the mean of all observations, and n – the number of observations. For pooled variance:

$$S_P{}^2 = \frac{(n-1)S_x^2 + (m-1)S_y^2}{n+m-2} \tag{4}$$

where S_p^2 is the pooled variance, n – the sample size for first sample, m – the sample size for second sample, S_x^2 – the standard deviation of Sample 1, and S_y^2 – the standard deviation of Sample 2. For t-test:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{S_p^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \tag{5}$$

where $\overline{x}_1$ is the mean of Sample 1, $\overline{x}_2$ – the mean of Sample 2, S_p^2 – the pooled variance, n_1 – the number of observations of Sample 1, and n_2 – the number of observations of Sample 2.

Results and discussions

Distillation of essential oils of eucalyptus

The extraction of essential oils from two species of Eucalyptus *i.e.*, *Eucalyptus camaldulensis* and *Eucalyptus citriodora* were carried out by solar distillation system and controlled distillation system. In both systems water, cum steam distillation technique was applied to extract the essential oils from the leaves of *E. camaldulensis* and *E. citriodora*.

Distillation of essential oil using solar distillation system

Fresh leaves of *Eucalyptus camaldulensis* and *Eucalyptus citriodora* were subjected to water cum steam distillation using a solar distillation system. An average yield of essential oils of *E. camaldulensis* and *E. citriodora* were found 30.50 g and 58 g, respectively as shown in tab. 1. The flow rate of the distillate from the solar distillation system was found to be 3.5-4 L per hour for peak hours. The percentage of *E. citriodora* essential oil was found to be 1.16%. These results were in agreement with findings from study effects of seasonal variations on yield and composition of *E. citriodora* essential oils [38]. Percentage of *E. camaldulensis* essential oils yield was found to be 0.61%. These results were in the agreement with findings from chemical composition of essential oils extracted from two species of Eucalyptus [39].

Distillation of essential oil using control distillation system

Through control distillation system, average yield of essential oils of *E. camaldulensis* and *E. citriodora* was found to be 29 g and 60 g, respectively as shown in tab. 1. The flow rate of the distillate from controlled distillation system was found to be 6-6.5 L per hour for the maximum supply of natural gas. Percentage of *E. citriodora* essential oils yield was to be 1.2%. These results were in agreement with findings from study on effects of seasonal variations on yield and composition of *E. citriodora* essential oils [38]. Percentage of *E. camaldulensis* essential oil was 0.58%. These results were coherent with findings from a study present in literature [39].

Table 1. Yield of *E. Camaldulensis* and *E. Citriodora* essential oils using solar distillation system and control distillation system

Particulars	Solar distillation system		Control distillation system	
	E. camaldulensis	*E. citriodora*	*E. camaldulensis*	*E. citriodora*
Total weight of fresh leaves	5000 g	5000 g	5000 g	5000 g
Average yield	30.50 g	58.00 g	29.00 g	60.00 g
Essential oils percentage	0.61%	1.16%	0.58%	1.20%

Statistical analysis

Effect of solar distillation and controlled distillation systems on yield of *E. camaldulensis* and *E. citriodora* essential oil is presented in tab. 2. Eight replications for each treatment were carried out.

Table 2. Yield of *E. Camaldulensis* and *E. Citriodora* essential oils over both treatments

Sr. No.	*E. camaldulensis*		*E. citriodora*	
	The yield of oil against, T_1 [g]	The yield of oil against, T_2 [g]	The yield of oil against, T_1 [g]	The yield of oil against, T_2 [g]
1	35	23	57	55
2	28	30	54	65
3	27	24	53	56
4	23	33	55	54
5	34	35	65	63
6	33	27	62	58
7	33	31	55	65
8	31	29	63	64
Total	244	232	464	480
Mean	30.50	29.00	58	60

where T_1 is the distillation of essential oil using solar distillation system and T_2 is the distillation of essential oil using controlled distillation system.

Significance of mean values

Significance of mean values of *E. camaldulensis* essential oils against both treatments was determined by applying a t-test using $\alpha = 0.05$ as shown in tab. 3. From the t-test, it was concluded that mean values of *E. camaldulensis* essential oils were not significantly different. Similarly, significance of mean value of *E. citriodora* essential oils against both treatments was also presented in tab. 3. It was concluded that, mean values of *E. citriodora* essential oils were not significantly different from each other.

Table 3. The t-table for the significance of *E. camaldulensis* and *E. citriodora essential* oils yield

	E. camaldulensis essential oil		*E. citriodora* essential oil	
	T_1 [g]	T_2 [g]	T_1[g]	T_2 [g]
Replications	8.00	8.00	8	8
Mean	30.50	29.00	58	60
Variance	17.14285714	17.42857143	21.42857143	22.28571429
S.D	4.140393356	4.174754056	4.62910049	4.72077475
S.E	1.463850109	1.475998451	1.636634177	1.669045921
S_p^2	17.28571429		21.85714286	
t-value (calculated)	00.721568539		–00.85558526	
α	00.05		00.05	
ν	14.00		14.00	

where *S.D* is the standard deviation, *S.E* – the standard error, α – the level of significance, ν – the degree of freedom, S_p^2 – the pooled variance, and *t*-value (tab value), $t_{\alpha/2\nu} = 2.145$.

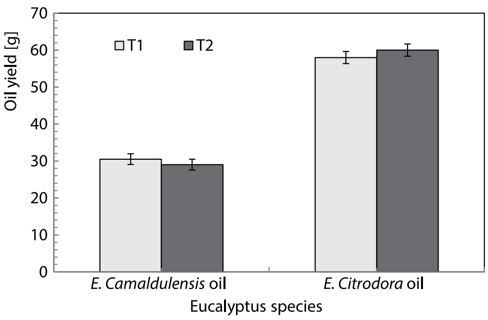

Figure 4. Representation of comparison between both treatments (solar distillation system and control distillation system)

Figure 4 compares the both solar and controlled distillation systems. From the t-test and fig. 4, it was found that there is no significant difference between solar and controlled distillation systems on the yield of essential oils. It was concluded that, both treatments had a similar effect on the yield of essential oils ofb considered species.

Analysis of essential oils using GC-MS analysis

The GC-MS analysis of E. camaldulensis essential oil

From GC-MS analysis, 38 and 36 peaks of *Eucalyptus camaldulensis* essential oils, distilled using a solar distillation system and controlled distillation system were identified, respectively. Pattern of gas chromatograph for *Eucalyptus camaldulensis* essential oils were found to be similar in the case of solar and controlled distillation systems as shown in figs. 5(a) and 5(b). The Principal constituents present in oil of *E. camaldulensis* were 1-8 cineol, γ-terpenes, sesquiterpene, monoterpene, α-pinene, and linalool. These results were coherent with the findings from a study present in [40].

The GC-MS analysis of Eucalyptus citriodora essential oil

From GC-MS analysis, 36 and 37 peaks of *Eucalyptus citriodora* essential oils, distilled using a solar distillation system and controlled distillation system were identified, respectively. Pattern of gas chromatograms for *Eucalyptus citriodora* essential oils were found to be similar in the case of solar and controlled distillation systems as shown in figs. 5(c) and 5(d). The principal compound of *E. citriodora* essential oil ~~is~~ was citronellal. These results were coherent with the available [41].

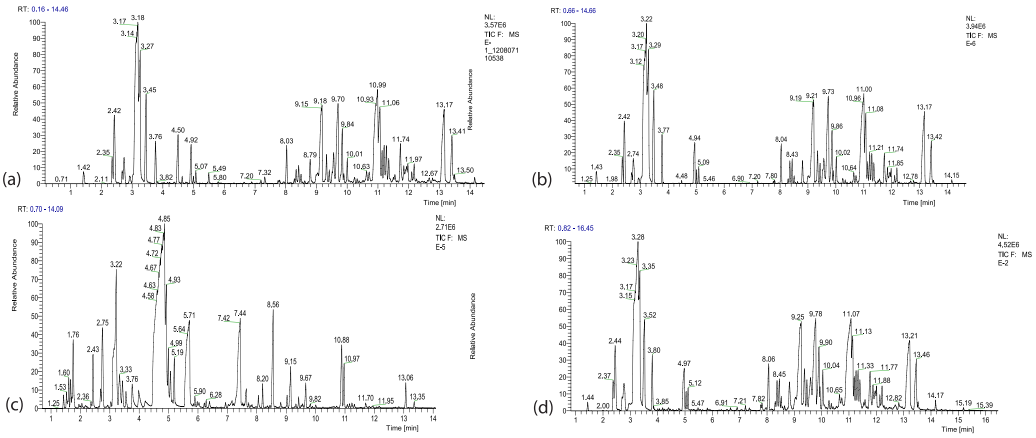

Figure 5. Gas chromatogram of (a) *E. camaldulensis* essential oil distilled using controlled distillation system, (b) Gas chromatogram of *E. camaldulensis essential* oil distilled using solar distillation system, (c) *E. citriodora* essential oil distilled by solar distillation system, and (d) *E. citriodora* essential oil distilled by controlled distillation system

Conclusions

This study focuses on the qualitative and quantitative analyses of essential oils of Eucalyptus leaves, distilled by solar distillation system and controlled distillation system. The results showed that there is no significant difference between the yields of esseentila oils, distilled by solar distillation system and conventional controlled distillation system. The solar distillation system was also operated undere different climatic conditions but found no significant difference in the yield of essential oils. So, on the basis of results, It was concluded that solar distillation system is identical to the controlled distillation systems that are already being used for the distillation of essential oils from araomatic and medicinal plants. So, the application of solar distillation system is the best opportunity to use the solar energy for the on farm processing of medicinal and aromatic plants. It was also found that the pattern of gas chromatographs of essential oils, distilled by both solar and controlled distillation systems were almost similar. The solar distillation system which was used in this study was batch type distillation system. According to this, it is suggested that to make use of solar energy as much as profitable, another still might be used, and the greenhouse effect might be introduced in the secondary reflector to minimize the energy losses from the lower part of the still which is exposed to solar radiations.

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