Development of a solar distillation system for essential oils extraction from herbs

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INTRODUCTION

Essential oils and aromatic plants have long been used throughout the world in foods, fragrances, perfumery, cosmetics and medicines. In the last decade, these potent natural remedies have gained enormous popularity in industrialized countries as well particularly in the multi-million-dollar aromatherapy business. Essential oils are often extracted from the flowers, leaves and roots plants. A single ounce of most essential oils has worth thousands of dollars. Different techniques are used for essential oils extraction like hydro & steam distillation, cold pressing/expression, maceration and solvent extraction etc. Out of all these methods, the distillation methods have advantage of extracting pure and refine essential oils by evaporating the volatile material and retaining the poison and harmful ingredients within the plant material. (Malle and Schmickl, 2005).Extracting essential oil requires a distillation process that traditionally uses large, centralized equipment which is unmanageable for even groups of farmers in most developing countries. Further, some essential oil comes from extremely delicate flowers that must be processed soon after harvesting. Thus, for functional and economic reasons, there is a need for small-scale, decentralized steam distilling equipment. Examples of plants that are distilled for essential oil are Peppermint, Lemon Balm (Melissa), Lavender, Cumin, Cloves, Anise, Caraway, Cassia and Fennel Seeds etc.

The limited availability of fossil fuel and their environmental impact, have led to a growing awareness of the importance of renewable energy sources especially in the tropical countries. The maximum Flux of incident radiant energy available is approximately 1100 W/m^2 without optical concentrating (Duffie & Beckman, 2006.).Although various kinds of solar collectors are in use yet their applications are restricted to drying and low temperature water boiling for heating houses and swimming pools etc. Various industrial surveys show that up to 24 per cent of all industrial heat, directly used in the processes, is at temperatures below 180 °C. (Garg, 2006, p. 229).The main object of the research is to introduce the solar energy in medium temperature agro-based industrial processing. The on-farm Extraction technique of essential oils from different fresh herbs using "Portable Scheffler Solar Concentrator" extracts the fresh contents of the oils as well as reduces the dependence on the conventional fuels in the domestic sector. Keeping all factors in view, the research has been initiated to introduce the innovative form of solar renewable energy and environmental technologies in the field of agricultural engineering and processing by developing a solar distillation system for essential oil extraction system from different herbs. In this paper, the detail of solar distillation for Cumin is discussed.

MATERIAL AND METHODS

Laboratory experiments were conducted using small scale distillation system. The apparatus consisted of electric heater of 250 watts, round glass boiler having 2 liters capacity, glass still tube, condenser and Florentine flask. In each experiment, 100 gram of the herb material was used with 1 liter of water. The electrical connections to the heater were provided through energy meter EC 3000.In the process, the water vapors along with volatile component of the material flows through still vessel and then condense. The condensed water and oil flows into Florentine flask where the oil generally having a specific gravity less than water, floats to the surface and is collected. Temperature distribution, quantity of water evaporated

and quantity of oil extracted during the distillation process for essential oils extraction were recorded at constant power of 250 watts. The laboratory data lead in design and development for solar distillation unit.

Scheffler's Fixed Focus Concentrator

The trailer mounted Scheffler collector was placed at "Solar Experimental Site" of University of Kassel, Witzenhausen. The Scheffler concentrator comprises of a primary reflector, a secondary reflector, and a clock mechanism powered by gravity. The primary reflector has 8 m^2 aperture area and produces a converging beam of sunlight on the secondary reflector having 0.434 m^2 surface area. The clock mechanism keeps the reflected beam aligned with the axis of rotation as the sun moves. The fixed secondary reflector reflects the beam from the primary reflector onto a target heating spot. Each morning, the primary reflector has to set back to a starting position in which the secondary reflector is illuminated to start the clockwork. After a few days, the angle between the axis of rotation and the reflector is to be adjusted to accommodate the seasonal variation in the height of the sun. The above mentioned whole system is fitted on a trailer foundation oriented in North–South direction. The latitude angle for Witzenhausen was set at 51°.

Experimental Setup

On the basis of results obtained from laboratory experiments and from evaluation of Scheffler collector, the distillation unit was fabricated in Agricultural Engineering Workshop Deula, Witzenhausen. A cylindrical black colored steel tank of 30 liter capacity was selected as a boiler having dimensions 0.340 m^2 in diameter and 0.340 m^2 in length. A rubber flexible pipe diameter 25 mm pipe connects the top of the boiler to a glass condenser. A Florentine flask having 200 ml capacity was used to separate the oil from water. In order to assess the continuous performance of the Scheffler's Concentrator during distillation experiments, three connections of K-type and T-type thermocouples were used to record receiver inside temperatures, water temperature and steam temperature of the distillation unit. All the three connections were attached to computer via data recording machine. The intensity of solar radiations was recorded with the help of Pyranometer.

RESULTS AND DISCUSSION

Figure 1 illustrates the complete distillation process for essential oils extraction for Cumin. The laboratory experiments were conducted at constant power of 250 Watts, so the data were recorded for process temperature (ºC) and quantity of oil extracted (mm) and percentage of total oil extracted (mm) with respect to energy (kWh).

It is evident from figure 1 that there is constant increase in temperature with respect to energy up to 100 ºC (sensible heat zone). Thereafter, the temperature line becomes parallel to abscissa till the end of the experiment. It is also clear from Figure 1 that there is gradual increase in oil extraction in latent heat zone. Against energy level of 0.85 kWh, 100% oil (1.7 ml) was extracted. After this limit, there was no rise in the level of oil. So 0.85 kWh is the optimum energy for the distillation process of 100 gram Cumin.
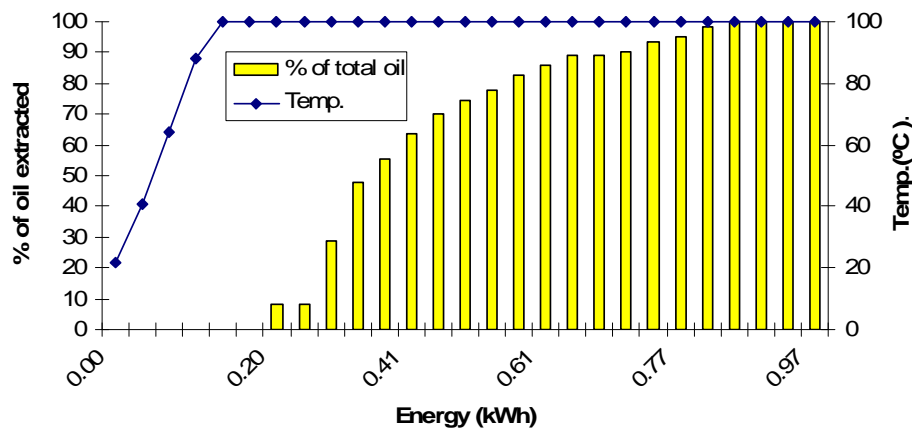

Figure 1: Temperature and percentage of total oil extracted during laboratory distillation process.

Performance Evaluation of Solar System for Distillation Process:
Different experiments were made to evaluate the performance of the Scheffler Concentrator by recording receiver inside temperature, water & steam temperature and solar radiations. From these data, energy (in sensible and latent heat phase) and power were calculated by using the followings relations.

$$Q_s = m_w\, c_p\, \Delta T$$

Where Q_s is sensible heat (k Joules), m_w is the mass of water in kg, c_p is the specific heat at constant pressure (For water = 4.187 k Joules. kg^{-1}. K^{-1}) and ΔT is the change in temperature (K) for a specific time.

$$Q_L = m\, L_{fg}$$

Where Q_L is the latent heat (k Joules), m is the quantity of water evaporated (kg) in specific period of time and L_{fg} is the specific latent heat of vaporization (For water = 2260 k Joules.kg^{-1}). Power (kW) was calculated by dividing these values with specific time interval. Figure 2 illustrate the variation of water temperature, receiver inside temperature and solar radiations on a sunny day of August 5, 2007 from 1207 to 1400 hours. In this performance evaluation test with 20 liter of water, 2 liter and 5 ml water was evaporated.
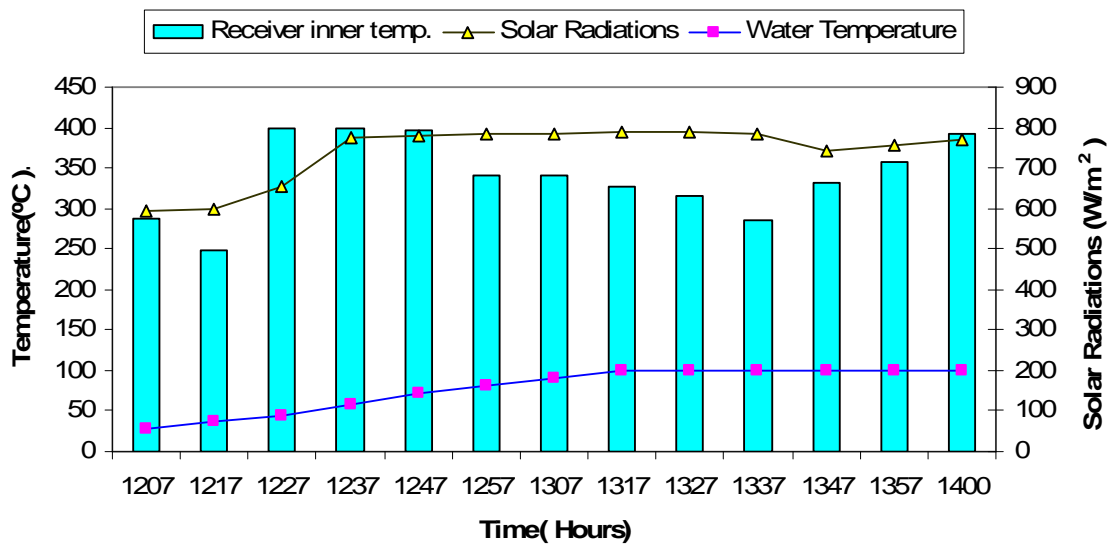

Figure 2: Variation of solar radiations, receiver inner temperature and water temperature.
During this test, the average value of power in terms of water boiling test was calculated to be 1.58 kilowatts. The system efficiency was calculated as 26.73 % against an average value of solar radiations (739 Watts/m^2). This efficiency figure relates to the perfection of the reflector surface area, its reflectance, absorptance of the outer surface of the distillation tank exposed to radiations and insulation of the remaining surface. Another trial was made with cooking oil to see the maximum temperature of other liquids. There was a uniform rise in temperature from 23 ℃ to 250 ℃ with respect to time and then the heavy vapors were observed showing phase transformation at high temperature. So it can be concluded that the Scheffler Concentrator can not only be used to evaporate the water but also equally good for processing with other liquids and cooking oils.

Development of Solar Distillation System:
The different parameters recorded during the experiment with solar distillation for 400 gram of cumin per 10 liter of water is explained in Table 1.

Table 1: Different parameters recorded during solar distillation for Cumin (Aug, 24, 2007)

Time (Hours)	Solar Radiations (W/m^2)	Water Temp (℃)	Total Energy (kWh)	Total Energy (kWh) Per 100 gram	Ave. power (kW)	Essential Oil (ml)	Essential Oil (ml) Per 100 gram	% of total oil
1532	558	21	0.00	0.00	-	0.00	0.00	0.00
1542	701	39	0.21	0.05	1.26	0.00	0.00	0.00

1552	731	62	0.48	0.12	1.61	0.00	0.00	0.00
1602	711	89	0.79	0.20	1.88	0.00	0.00	0.00
1612	717	100	0.99	0.25	1.19	0.68	0.17	16.75
1622	682	100	1.22	0.31	1.41	0.95	0.24	23.40
1632	715	100	1.48	0.37	1.51	1.22	0.31	30.05
1642	703	100	1.70	0.42	1.32	1.85	0.46	45.57
1652	692	100	1.93	0.48	1.39	2.43	0.61	59.85
1702	676	100	2.15	0.54	1.34	2.43	0.61	59.85
1712	659	100	2.40	0.60	1.49	2.97	0.74	73.15
1722	668	100	2.62	0.65	1.32	3.38	0.85	83.25
1732	665	100	2.83	0.71	1.28	3.65	0.91	89.90
1742	360	100	3.01	0.75	1.05	4.06	1.02	100
1752	242	100	3.19	0.80	1.11	4.06	1.02	100
1802	116	95	3.20	0.80	0.02	4.06	1.02	100

It is clear from Table 1 that 100 % oil was extracted at 1742 hours. The quantity of oil extracted was 4.06 ml against total energy consumption of 3.01 kWh. Although this experiment was conducted in the evening time of low solar radiations hours yet the temperature and energy requirements for distillation process of Cumin were quite satisfactory as shown in Figure 3 and can be compared with laboratory method (Fig. 1).
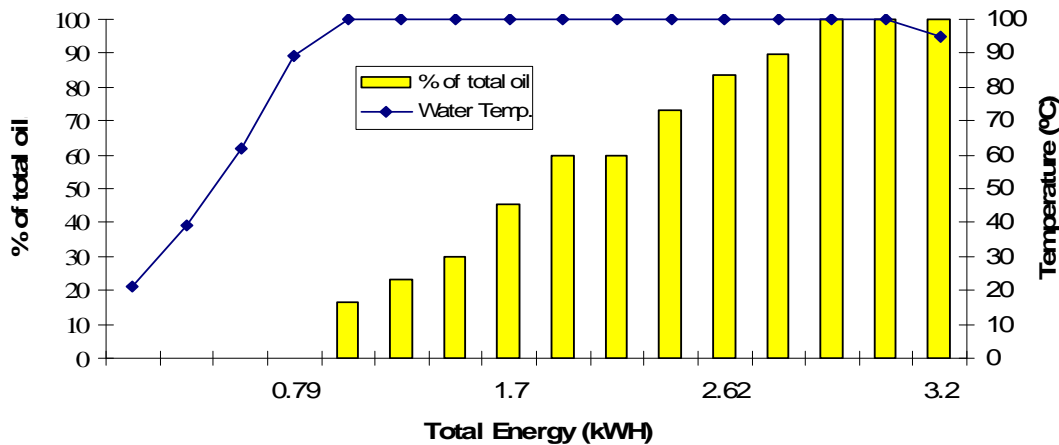

Figure 3: Variation of temperature and percentage total oil extracted during solar distillation
The distillation process for essential oil extraction utilized approximately same heat energy per unit weight of the herb. The results show that complete distillation process for essential oils extraction can be done successfully using Scheffler fixed focus concentrator without using any auxiliary energy. However, extraction was comparatively low suggesting a little modification in the existing distillation unit.
CONCLUSIONS AND RECOMMENDATIONS
On a sunny day with an average global radiations figure of 739 W/m2, the output power and system efficiency during distillation process using Scheffler fixed focus concentrator were calculated as 1.58 kW and 26.75 % respectively. All thermal parameters were quite similar to that of laboratory experiment for Cumin. It is concluded that solar distillation process for essential oils extraction can be successfully carried out using Scheffler fix focus concentrator. However, the difference in extraction suggests minor modification in the existing distillation to enhance its extraction efficiency.
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