Solar distillation for essential oils extraction - a decentralised approach for rural development

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1. Abstract

A large part of industrial process heat lies from low to medium temperature range which can be supplied by solar energy. The promotion of decentralized agro-based industries by using innovative solar collectors can open new landmarks in rural development especially in tropical countries. Essential oils extraction from herbs through distillation process is one of the medium temperature agro-based industries. These oils are used in food, medicines, fragrances, perfumery and cosmetics. Scheffler fixed focus concentrators provide the required temperature range for solar distillation systems. The system is installed at solar campus, University of Kassel, Witzenhausen to avail fresh supply of different herbs. In the first phase of the research, several trials were made to evaluate the performance of the system. Within the beam radiations range of 700-800 Wm^{-2}, the receiver temperatures were recorded between 300-400°C. All kinds of herbs were processed successfully by using solar distillation system.

Keywords**:** Essential oils, herbs, Scheffler concentrator, solar distillation, beam radiations

2. Introduction

The limited availability of fossil fuels and their environmental impact, have led to a growing awareness of the importance of renewable energy sources especially in the tropical countries. The available flux of incident radiant energy is approximately 1100 W/m^2 without optical concentrating (Duffie & Beckman, 2006). Various industrial surveys show that up to 24 per cent of all industrial heat, directly used in the processes, is at temperatures from ambient to 180 °C (Garg, 2006). At present, various types 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. The main object of the research is to introduce the solar energy in medium temperature agro-based industrial processing. Essential oils extraction techniques from fresh herbs using decentralised solar distillation system not only minimize the losses of volatile essence of the plant material but also reduce the dependence on the conventional fossil 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 food processing by developing a solar distillation system for essential oil extraction from herbs.

3. Background

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 oil extraction from herbs is one of the medium temperature agro-based industries that can play a vital role in promoting agriculture and farmer's living standard. 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 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 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 leaves and flowers that must be processed soon after harvesting. Thus, for functional, economic and environmental reasons, there is a need of decentralized steam distillation equipment. Examples of plants that are distilled for essential oil are Peppermint, Lemon Balm (Melissa), Lavender, Cumin, Cloves, Anise, Caraway, Cassia and Fennel Seeds, Rosemary etc.

4. Project description

The research comprises of two phases, laboratory experiments followed by field experiments with solar energy.

4.1 Laboratory experiments

Laboratory experiments were conducted using small scale distillation unit. The apparatus comprises of insulated electric heaters (0-500 W), round glass boilers having 2 liters capacity, glass still tubes, condenser units and Florentine flasks. In each experiment, similar parameters were maintained for comparison. The electrical connections to the heater were provided through energy meter. In the process, the water vapours along with volatile component of the material flow 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. The heat energy consumptions and temperatures were recorded under identical conditions for different herbs. The data were recorded for process temperature (ºC), quantity of oil extracted (mm) and percentage of total oil extracted with respect to energy (kWh). The laboratory data lead in design and development for solar distillation unit. Fig. 1 illustrates the complete distillation process for essential oils extraction from 100 gram Cumin.

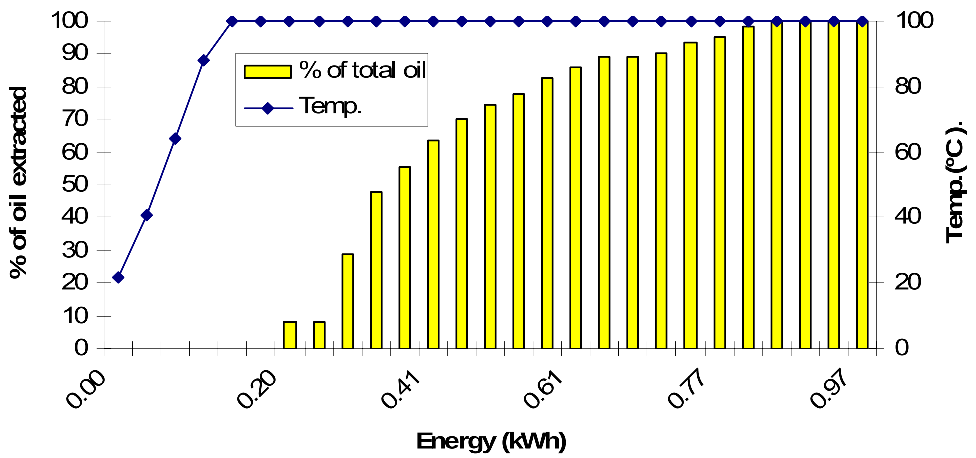

Fig. 1 Temperature and percentage of total oil extracted during laboratory distillation process (Cumin)

It is evident from Fig.1 that there is constant increase in temperature with respect to energy up to 100 ºC (sensible heat phase). 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 phase. 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. Similarly, optimum parameters were recorded for other herbs.

4.2. Experimental setup of solar distillation system

The system was installed at solar campus, University of Kassel, Witzenhausen, Germany to avail the supply of fresh herbs. Scheffler fixed focus concentrator was used for solar distillation system. The system comprises of a primary reflector (8 m^2 aperture area), secondary reflector, stainless steel boiler, condenser unit and Florentine flasks as shown in Fig. 2.

Fig. 2 Solar distillation system for essential oils extraction

The primary reflector rotates along an axis parallel to the earth axis of rotation by a precise photovoltaic tracking mechanism and keeps the reflected beam aligned with the fixed secondary reflector as the sun moves. The secondary reflector further reflects the beam radiation to targeted distillation bottom for the steam distillation. The system is equipped with thermocouples and Pyranometer to control and optimize the distillation processes. Different glass Florentine flasks were used to separate the oil from water. In order to assess the continuous performance of the Scheffler 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 beam radiations was recorded with the help of Pyranometer.

4.3. Performance evaluation of the solar distillation system

Several experiments were conducted to evaluate the performance of the solar distillation system by recording receiver inside temperature, water & steam temperature and solar radiations. From these data, energy in sensible heat (Q_s), latent heat phase (Q_L) and power were calculated by using the followings relations.

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

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

$Q_L = xm \, L_{fg}$

Where Q_L is the latent heat (kJoules), x is the dryness fraction, 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 kJoules.kg^{-1}). Within the solar radiations range of 700-800 W/m^2, the receiver temperatures were recorded between 300-400°C. Fig. 3 illustrates the variation of water temperature, receiver inside temperature and solar radiations on a sunny day from 1207 to 1400 hours.

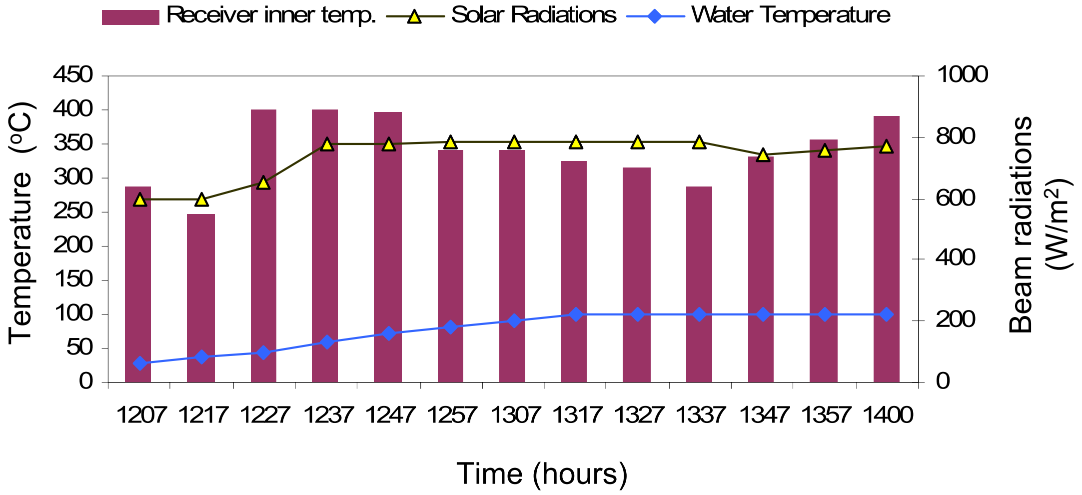

Fig. 3 Variation of solar radiations, receiver inner temperature and water temperature

In this performance evaluation test with 20 liters of water, 2.005 ml water was evaporated. The average power and efficiency in terms of water boiling test was calculated to be 1.58 kilowatts and 43.25 % respectively against an average value of beam radiations (739 Watts/m^2). This efficiency figure relates to the perfection of the reflector surface area, its reflectance, absorbance of the outer surface of the distillation tank exposed to radiations and insulation of the remaining surface. Trials were also made with cooking oil to see the maximum temperature of other liquids. There was a uniform rise in temperature from 23 ºC to 250 ºC with respect to time and then the heavy vapours 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. Different herbs like Melissa, Peppermint, Lavender, Fennel seeds, Cumin, Basil, Cloves buds and rosemary etc were processed successfully by using solar distillation system. Fig. 4 explains the solar distillation for 400 gram of cumin per 10 liters of water.

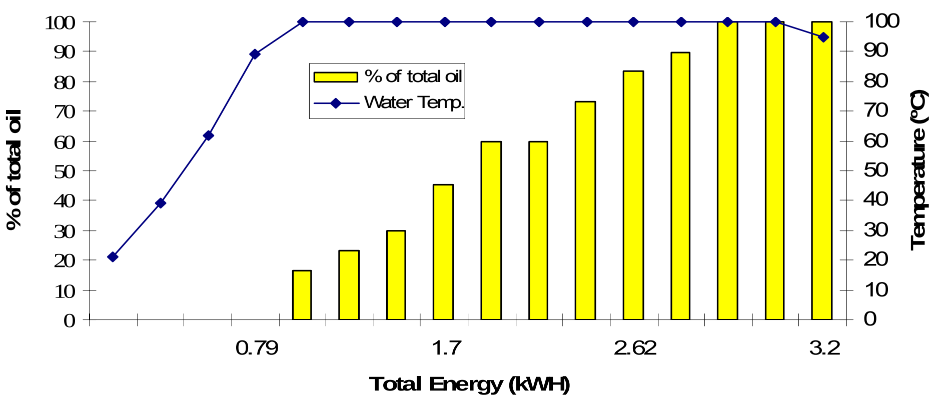

Fig. 4 Variation of temperature and percentage total oil extracted during solar distillation (Cumin)

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 Fig. 4 and can be compared with laboratory method (Fig. 1). The solar distillation process for essential oil extraction utilized approximately same heat energy per unit weight of the herb. The results show that completes distillation process for essential oils extraction can be done successfully using Scheffler fixed focus concentrator. In sunny days, 4-5 batches can be processed up to 10 kg per batch. These results were found similar to laboratory results showing that solar distillation can be successfully used for extraction of essential oils.

5. Conclusions

The present study was conducted with one of most temperature sensitive process industry using solar energy. All kind of herbs were processed successfully by using solar distillation system. In the several tests, all thermal parameters were found quite similar to that of laboratory experiment. It is concluded that solar distillation of essential oils extraction can be successfully carried out using Scheffler fixed focus concentrator. This study also concludes that these types of innovative solar concentrators can open new landmarks in decentralised solar based systems especially in food and post harvest sector. In addition, other benefits like reduction of fossil fuels consumption and global warming cannot be ignored. The study also suggests that such types of systems must be equipped with necessary mountings and instrumentations to monitor and control the desired thermal parameters during temperature sensitive industrial processing.

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