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Biomass energy utilization in solar distillation system for essential oils extraction from herbs

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Introduction

Utilization of solar energy in agriculture provides an extraordinary opportunity to promote small scale agro-based industry especially in tropical countries. Innovative solar collectors have opened several fields of applications of solar thermal energy at a medium and medium-high temperature level in post harvest and food processing. Essential oils extraction from herbs is one of the medium temperature agro-based industries.

These oils are used in medicinal and pharmaceutical purposes, food and food ingredients, herbal tea, cosmetics, perfumery, aromatherapy, pest, and disease control, dying in textiles, gelling agents, plant growth regulators and paper making (Öztekin & Martinov, 2007). These oils are very expensive and a single ounce of most of the oils has worth thousands of Dollars. In the last decade, these oils remedies have gained enormous popularity in industrialized countries as well particularly in the multi-million-dollar aromatherapy business. Essential oils often extracted from the flowers, leave and roots plants, are an especially good solution to this problem. Out of all extraction methods, the distillation methods have advantages of extracting pure and refine essential oils by evaporating the volatile essence of the plant material (Malle and Schmickl, 2005). At present, there are often large and centralized distillation units mostly located in city areas. Due to their high operating costs, these are unmanageable by farmers or even groups of farmers in most of the developing countries. Further, some essential oils come from extremely delicate flowers and leaves that must be processed soon after harvesting. Thus, for functional, economic and environmental reasons, there is need of an on-farm solar distillation unit.

Various industrial surveys show that up to 24 percent of all industrial heat, directly used in the processes, is at temperatures below 180°C. In several industries, 100 percent process heat requirement is below 180°C which can be supplied economically by evacuated tube collectors and solar concentrators (Garg & Prakash, 2006). A solar distillation system was developed using Scheffler fixed-focus concentrator but it worked effectively only during sunny days (Munir & Hensel, 2009). The degree of reliability desired of a solar process to meet a particular load can be provided by a combination of properly sized collector and an auxiliary energy source. In the most climates, auxiliary energy is needed to provide high reliability and avoid gross over design of the solar system (Duffie & Beckman, 2006). For this purpose, solar distillation system was integrated with biomass energy to operate during adverse climatic conditions. The auxiliary biomass system comprises of a boiler, biomass furnace, and economiser and equipped with all safety mountings and fittings. The boiler operates under natural draught with the help of a chimney for efficient combustion process and can be operated with firewood, bagasse, spent and other biomass material etc. The main object of the work is to utilize solar energy as a primary heat source and the rest is provided by biomass boiler. The steam connection of the biomass boiler is injected into the distiller while bottom of the distiller is always exposed to beam radiations coming from the fixed-focus solar concentrator. The paper presents the development and experimental results of solar distillation system integrated with biomass energy for on-farm extraction of essential oils.

Solar based distillation system

The solar based distillation system comprises of a primary reflector, a secondary reflector, and a PV tracking device. The primary reflector has 8 m^2 aperture area and produces a converging beam of sunlight on the secondary reflector. The tracking device 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. 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 installed at “Solar Experimental Site” of University of Kassel, Witzenhausen (Latitude, 51°).

A cylindrical stainless steel distillation still of 1210 column height and 400 mm diameter was used for distillation experiments. A stainless steel pipe having diameter 50 mm pipe connects the top of the boiler to a stainless steel condenser. Florentine flasks were used to separate the oil from water. In order to assess the continuous performance during solar 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 logger. The intensity of solar radiations was recorded with the help of Pyranometer. The distillation unit can be operated for water and steam distillation. The power available and efficiency during distillation process were found to be 1.55 kW and 33.21 % respectively from the sensor system installed.

Need of auxiliary energy in solar distillation system

The solar distillation system worked quite effectively during sunny hours as it is operated by a concentrated solar collector. This system can be successfully used in tropical countries all over the world. The present study was conducted in Witzenhausen, Germany (Latitude 51.3°) where sunny days are not so often. Many distillation experiments were suffered adversely during bad weather conditions. As the present research was conducted without any energy storage consideration, so the temperature during distillation process drops rapidly with the drop of beam radiations as shown in Figure 1.

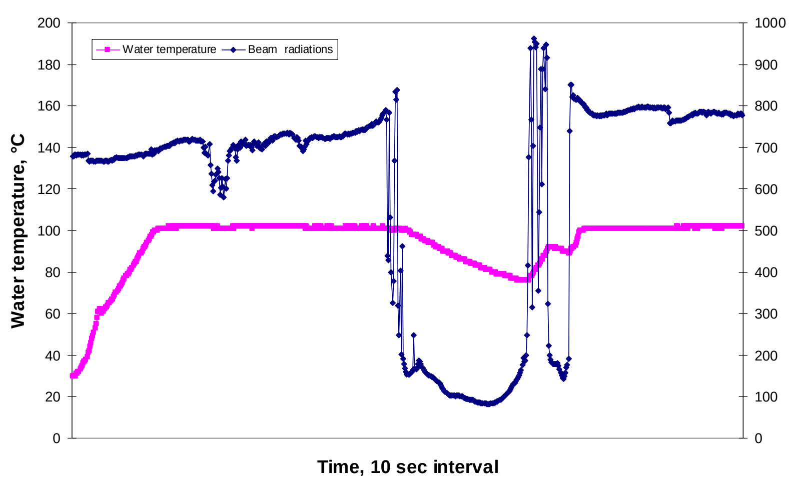

Figure 1. Variation of distillation temperature and beam radiation with time

It is evident from Figure 1 that under constant range of beam radiations 700-800 W/m^2, the distillation temperature curve is quite stable at 100°C. In low solar intensity ranges, the temperature drops down below 100° C showing the steam production for distillation process has stopped.

The degree of reliability desired of a solar process to meet a particular load can be provided by an auxiliary energy source. By keeping all these facts in view, the existing solar system is connected with the biomass energy to continue the distillation process all the time.

Construction and operation of biomass steam generator

The present study is carried out to utilize solar renewable energy for on-farm distillation of essential oils from herbs. Biomass fuels are easily available and free of cost on the farms. For this purpose, a small scale biomass boiler was developed as an auxiliary heat source to compensate for distillation process during adverse climatic conditions at the site. The complete biomass system is fabricated in the university workshop. The boiler is a single tube vertical boiler type and is designed only to hybrid the solar distillation system. The boiler comprises of a vertical shell (360 mm diameter and 400 mm height), biomass furnace, and economiser (360 mm diameter and 1 m height) and is equipped with all safety mountings like safety valve, water level indicator, and blow off valve. The furnace is provided with arch with gradual increasing area on top which opens in combustion chamber. A chimney passes though the center of the boiler and economizer and exhausted to atmosphere. Firewood, bagasse, chaff husk or other spent biomass materials can be used as fuels in the furnace. As a result of combustion, the heat energy is transferred to the bottom of the shell and the burnt biomass is dropped down at the ash pit in the form of ash for continuous boiler operation. The flue gases pass through the chimney first transferring the heat to boiler and then to the economizer as shown in the Figure. 2

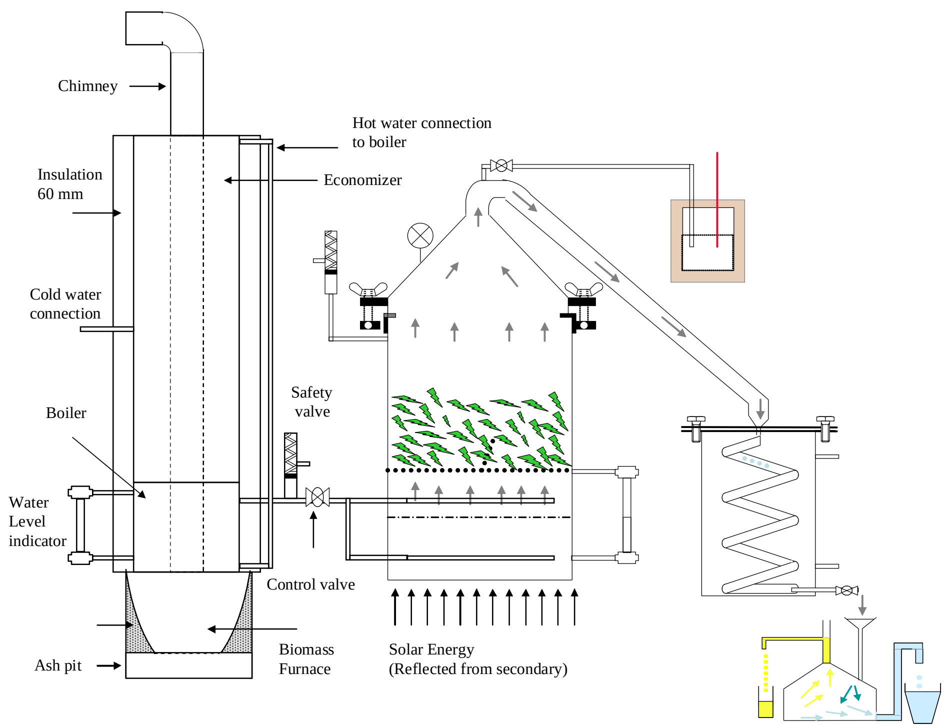

Figure 2. Schematic of solar biomass distillation system

As a result of heat transfer to the economizer from flue gases, hot water rises in the economizer due to density difference. In order to utilize the hotter water of the economizer, feed water connection for the boiler is taken from the top of the economizer while the economizer is filled by overhead pressure. Water is fed into the boiler at saturation temperature for quick generation of steam which can be used for different distillation process.

In order to equally distribute the steam in the distillation still, two steam coils are provided in the distillation still. Small holes are drilled on the top and sides of the coils. The upper coil is used for steam distillation and the lower coil is used for water distillation in the absence of solar energy. Both coils are connected to the boiler via a wire-braided high pressure hose. The main object of the work is to utilize solar energy as a primary heat source and the rest is provided by biomass boiler. The bottom of the distillation still is always exposed to beam radiations reflected from secondary reflector of Scheffler fixed-focus solar concentrator while the biomass system provides steam through stop valve to make up any deficiency of steam. The required steam flow rate was maintained by monitoring the condensate flow rate. The detail of the whole system is shown in Figure 2.

The boiler was hydraulically tested at 5 bar pressure before the steam trials. The system was design to run maximum 0.5 bar pressure but most of the distillation experiments are carried out under atmospheric pressure.

Results of solar distillation system with auxiliary biomass furnace

Several experiments were carried out during adverse climatic conditions using solar energy integrated with biomass energy. During hybrid solar distillation experiments, the distillation still was filled with water to produce steam by reflected beam radiations on the still bottom and the extra energy was taken from the biomass boiler. The experiments were conducted with different plant material like Melissa, Peppermint, Lavender, Abies alba, etc. The examples with 10 kg of Peppermint are shown in the Figure. 3

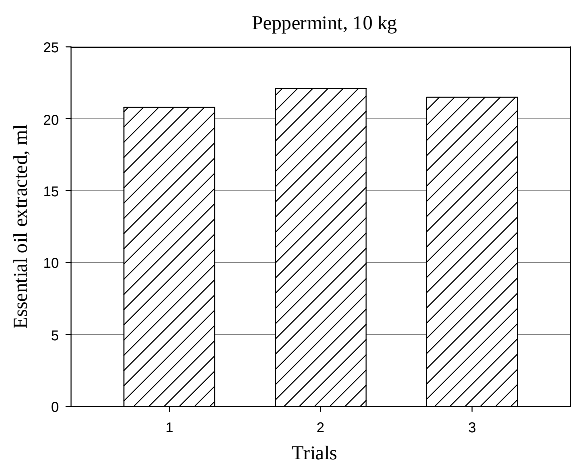

Figure 3. Results of solar biomass hybrid system for 10 kg Peppermint

The average amount of oil extracted was 21.46 ml with standard error 0.375. Low value of standard error shows that the results obtained under different conditions are quite similar. These results were also found similar as obtained by solar trials. In order to recover energy from the solar distillation system hybrid with biomass energy, condenser outlet water was reused to maintain the level in the distillation still and to recharge new batches. The water temperature achievable is about 85°C and was recycled when required. In this way, quick steam generation is started which in turn consume less time and energy during the processing. The results reveal that biomass energy can be successfully utilized in the solar distillation system. It also provides to operate the distillation unit during adverse climatic conditions.

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