SOLAR ASSISTED DRYING SYSTEM

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Abstract

A solar assisted drying system has been designed, fabricated, and evaluated. The main components of the drying system consist of a solar collector, an energy storage tank, an auxiliary heater, two blowers, two adsorber columns, two water-air heat exchanger, two water circulating pumps, a drying chamber and other ancillary equipment. The solar collectors used were 60-evacuated heat pipes tube arranged in parallel with total area of 6 m^2. The area of absorber in tube each individual was 0.1 m^2, and distance between the tubes was 7.1 cm. The objective of this study is to evaluate the contribution of solar energy to drying system for drying Centella Asiatica L (heat sensitive product). A computer program was developed in MATLAB software to calculate the contribution of solar energy to drying system. The results found that the total energy required by drying system for drying Centella Asiatica L from initial weigh of 3 kg to final weigh of 0.37 kg over drying time of about 12 hours at an air velocity is 3.25 m/s was found 47609 kJ. This energy contributed by solar collector, auxiliary heater and pump and blower of about 25315 kJ, 17829 kJ and 4464 kJ, respectively. The maximum values of solar fraction (SF) was found 97 %.

Key-words: - *Contribution of solar energy; Dehumidification; Drying of Centella Asiatica L;*

INTRODUCTION

Centella Asiatica L is an ethnomedical plant used in different continents by diverse ancient cultures and tribal groups [1] as a medicinal herb that is heat sensitive. *Centella Asiatica* L could be used for wound healing, anti-allergic, anticancer, anti-diarrheic, cooling drink, relief of heatiness [2]. These properties have been ascribed to the active ingredients in *Centella Asiatica* L: Asiatic acid, asiaticoside, madecassic acid and madecassoside [1].

The *Centella Asiatica* L after harvesting must be dried as soon as possible to preservation. Moisture content of the *Centella Asiatica* L reduced to certain levels for inhibits microbial growth and enzymatic modifications. Beside removal of moisture content the quality of the dried product and drying time must be taken into consideration [3].

In many countries, conventional hot air drying method is commonly used for drying foods or other heat sensitive, biologically active products. Although the method is very cheap and practice, however the conventional hot air dryers which are clearly not suitable to dry them because the high drying air temperature may remove important ingredients and degrade the product resulting in low product quality [4].

Solar assisted drying system is an alternative method for drying of foods or other heat sensitive, biologically active products. Because of this system operated with less relative humidity and lower temperature. The objective of this study is to evaluate the contribution of solar energy to drying system for drying *Centella Asiatica* L. A computer program developed in MATLAB software to calculate the contribution of this energy.

2. DESCRIPTION OF SOLAR ASSISTED DRYING SYSTEM

A schematic diagram of the solar assisted drying system is shown in Fig 1. The main components of the drying system consist of a solar collector, an energy storage tank, an auxiliary heater, two blowers, two adsorber columns, two water-air heat exchanger, two water circulating pumps, a drying chamber and other ancillary equipment. The solar collectors used were 60-evacuated heat pipes tube arranged in parallel with total area of 6 m^2. The area of absorber in tube each individual was 0.1 m^2, and distance between the tubes was 7.1 cm. The pump electrical capacity was 0.1 kW and was used to circulate water from the water tank to the solar collectors. The water tank with diameter of 45 cm and height of 85 cm was made from stainless steel and insulated using glass wool and foam rubber. Two units of cross flow type heat exchanger have been used. This system has two adsorber columns with dimension of 25 cm (width) x 25 cm (length) x 100 cm (height). The columns were filled up with silica gel to a height of 85 cm. The drying chamber was of the cabinet type with the size of 1.0 m (width) x 1.0 m (length) x 2.5 m (height). The chamber contains the drying trays with adjustable racks to place the medicinal herbs. The dry air from the adsorber column entered the drying chamber at the bottom and exit through an air vent at the top. The dry air was circulated by using blower with electrical capacity of 0.75 kW. Water in the heat storage tank is recirculated in the solar collector by the heat collection pump and this recirculation eventually raises the water temperature in the tank. Since the water in the storage tank is utilized for both the regeneration of the absorbent at a higher temperature and the drying process at a lower temperature, a temperature level of about 70°C-80°C is required. If the solar collector could not raise the water temperature up to this level, then the auxiliary heater is used to supplement the heat energy required to do so. The hot water is first used to produce hot air in the hot water-air heat exchanger for regeneration of adsorbents in one adsober column, and to warm dehumidified air from the other adsorber column in the warm water–air heat exchanger for drying in the drying chamber by manipulation of the two three-way valves. Fresh air for both regeneration and adsoprtion/drying is drawn in by the two blowers.

The adsorbents are packed in two adsorber columns so that air dehumidification could run continuously by simultaneous bed regeneration and adsorption in alternate bed as follows. Regeneration of adsorbents in the adsorber column (B) is carried out by heating the air drawn in by the air blower (B) in the hot water-air heat exchanger (B) and passing the hot air into the adsorber column (B) so that moisture is desorbed and removed from the adsorbents into the atmosphere. At the same time, drying is carried out in the drying chamber by heating the air drawn in by the blower (A) that is dehumidified by adsorber column (A) in the warm water-air heat exchanger (A) and passing the warm dehumidified air into the drying chamber. When the adsorbents in the adsorber column (A) are saturated with moisture and the regenerated adsorbents in the other adsorber column (B) are fully regenerated, then the regeneration process is switched to the saturated adsorber column (A) and the adsorption process is switched to the another adsorber column (B) by manipulation of the two three-way valves.

3. THEORETICAL BACKGROUND

The contribution of solar energy to the drying system depends on performance of each component. By using mass balance and energy balance equations for each components are obtained equations as follows:

3.1 The solar collector

Arcuri et al. [5] presented an expression to describe the performance of a solar evacuated tube collector by an energy balance involving energy gain and thermal and optic losses as follows:

$$\dot{Q}_U = F_R\left((\tau\alpha)A_{Ct}I_T - \frac{(T_1 - T_a)}{R_{et}}\right) \qquad (1)$$

The useful energy $\dot{Q}_U$ collected by the water in term its temperature rise is also written as

$$\dot{Q}_U = \dot{m}_{WC}C_{PW}(T_2 - T_1) \qquad (2)$$

3.2 Adsorber columns

For dehumidification process:

$$R_{dh} = (X_{SGt} - X_{SGi})\frac{W_{SG}}{\Delta t} \qquad (3)$$

$$\dot{Q}_{ra} = \dot{G}_a C_{pa}(T_6 - T_5) \qquad (4)$$

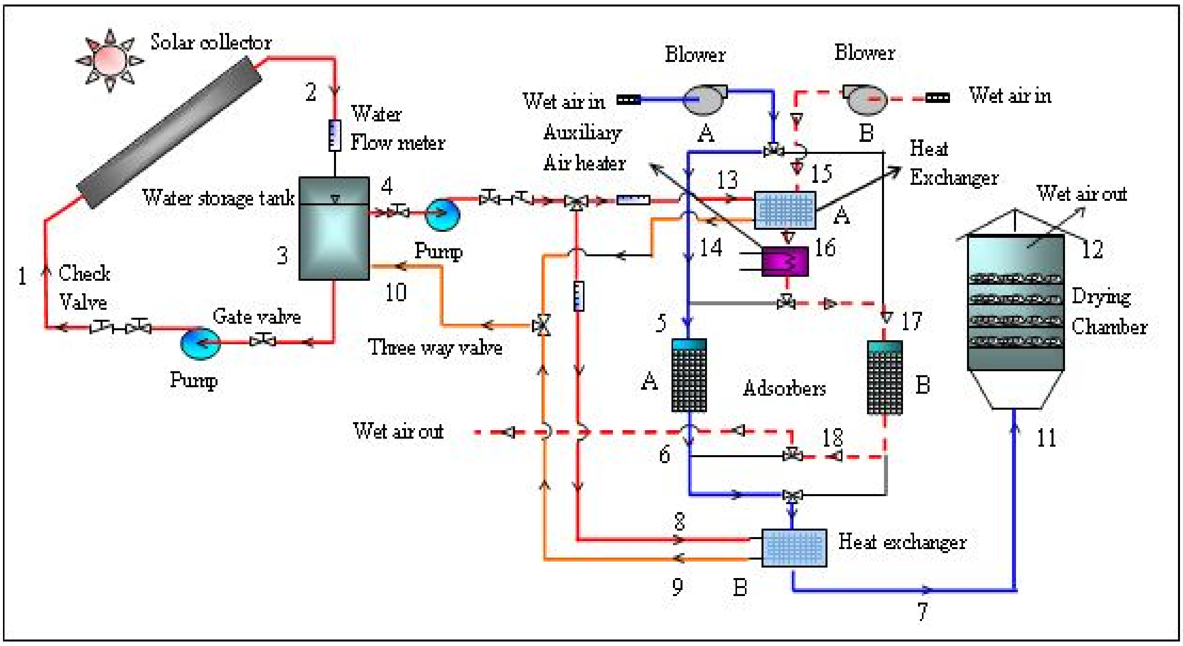

Figure1. Schematic diagram of the solar assisted drying system

For regeneration process:

$$R_{rg} = (X_{SGi} - X_{SGt})\frac{W_{SG}}{\Delta t} \quad (5)$$

$$\dot{Q}_{rg} = \dot{G}_a C_{pa}(T_{17} - T_{18}) \quad (6)$$

3.3 Drying chamber

For drying process:

$$\dot{X}_W = (X_{CAi} - X_{CAt})\frac{W_{CA}}{\Delta t} \quad (7)$$

$$\dot{Q}_W = \dot{G}_a C_{pa}(T_{12} - T_{11}) \quad (8)$$

$$\dot{Q}_W = \dot{X}_W H_{fg} \quad (9)$$

3.4 Heat exchangers H_{E1} and H_{E2}

$$T_{16} = T_{15} + \varepsilon(T_{13} - T_{15}) \quad (10)$$

$$\dot{Q}_{H1} = \dot{G}_a C_{Pa}(T_{16} - T_{15}) \quad (11)$$

and

$$T_7 = T_6 + \varepsilon(T_8 - T_6) \quad (12)$$

$$\dot{Q}_{H2} = \dot{G}_a C_{Pa}(T_7 - T_6) \quad (13)$$

3.5 Auxiliary air heater

$$\dot{Q}_{HT} = \dot{G}_a C_{Pa}(T_{17} - T_{16}) \quad (14)$$

3.6 Pump and Blower

$$\dot{W}_P = Q_P \Delta P_P \quad (15)$$

$$\dot{W}_B = Q_B \Delta P_B \quad (16)$$

3.7 Solar fraction

Solar fraction of the system can be defined as the ratio of the energy obtained from the solar collector to the energy required by the load [6]:

$$SF = \frac{\dot{Q}_U}{\dot{Q}_L} \quad (17)$$

Where:

$$\dot{Q}_U = \dot{Q}_{H1} + \dot{Q}_{H2} \quad (18)$$

$$\dot{Q}_L = \dot{Q}_U + \dot{Q}_{HT} + \dot{W}_P + \dot{W}_B \quad (19)$$

4. INSTRUMENTATION

In order to evaluate the contribution of solar energy to the drying system, measurements of temperatures, humidities, moisture contents, air velocities, static pressures, solar radiation on collector surface and on horizontal, mass and density of *Centella Asiatica* L sample were made during tests conducted. Dry bulb temperatures were measured with type-K thermocouples. Solid-state hygrometers were used to measure humidities at different locations. A hygrometer with type-K thermocouples was also used to measure dry-bulb and wet-bulb temperatures at selected locations in the dryer. These temperatures were used to obtain air humidities from psychometric charts. A turbine flow meter is used to measure the flow rate and velocity of the air. The flow rate of water is measured with the help of a water flow meter. The instantaneous solar radiation has been measured by using the Eppley Pyranometer and mounted near the collector on the plane of the collector. Static pressures were measured periodically by a U-tube micrometer. The moisture measurement in the product has been done with the help of a weighing machine. The power consumption of the system is measured by a wattmeter.

5. PROCEDURES

Fresh *Centella Asiatica* L was bought from the local market and cleaned thoroughly before use. The initial moisture content of the *Centella Asiatica* L sample was 88% wet basis. This sample was placed on a tray in the drying chamber. Weight loss of the sample was recorded every 15 minutes by a weighing machine located inside the drying chamber.

6. RESULT AND DISCUSSION

The drying process of fresh *Centella Asiatica* L with initial weight and initial moisture content of about 3 kg and of 88% wet basis, respectively was conducted in two days and each day was started at 10 am and continued till 4 pm. The *Centella Asiatica* L dried to final weight and final moisture content of about 0.37 kg and 15%, respectively at an air velocity is 3.25 m/s. The contribution of solar energy to drying system as shown in Figure (2-9).

The variation of solar radiation and ambient relative humidity during experimentation is shown in Fig.2. At the first day a maximum solar intensity of 972 Wm^{-2} was observed and the ambient relative humidity varied between 52% and 78% with an average of about 63%. For the second day a maximum solar intensity of 941 Wm^{-2} was observed and the ambient relative humidity varied between 53% and 78% with an average of about 65%.

Figs.3 and 4 show variations of drying chamber inlet and outlet air temperature and the corresponding relative humidity at inlet and outlet drying chamber respectively. As seen from figure the drying chamber inlet air temperature was maximum at noon and was about 50°C while the corresponding relative humidity was the minimum and it was about 20%. This stated that the drying air condition is suitable for drying heat sensitive product like *Centella Asiatica* L because of drying process conducted at low air temperature and low relative humidity.

Fig.5. show variation of the moisture content of *Centella Asiatica* L with time. Its moisture content in drying chamber was reduced from an initial value of 88 % wet basis to the final value of 15 % within 2 days or over drying time of about 12 hours.

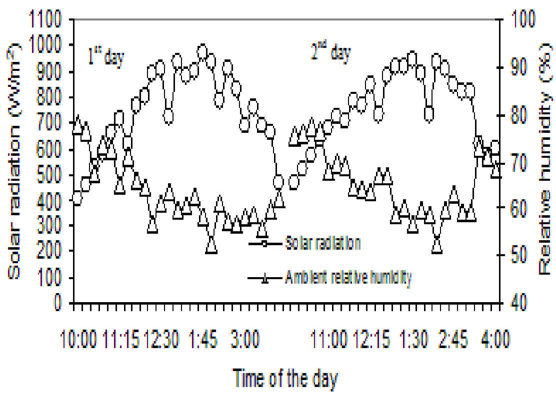

Fig. 2. Variations of solar radiation and ambient relative humidity with time.

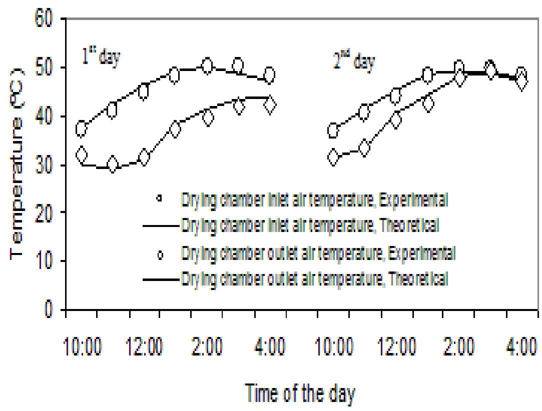

Fig .3. Variations of drying chamber inlet and outlet air temperatures with time.

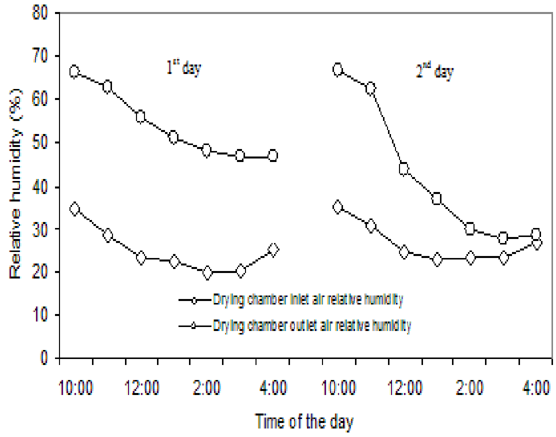

Fig. 4. Variations of drying chamber inlet and outlet air relative humidity with time.

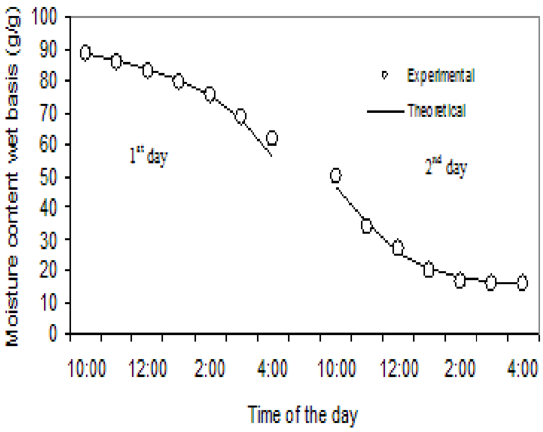

Fig.5. Variations of moisture content of *centella asiatica* L with time.

Figs.6 and 7 show variations of energy contribution for drying process and regeneration process respectively. As seen from figure that both these process, the energy contributed by auxiliary heater corresponding with energy contributed by solar collector. The energy contributed by auxiliary heater decreased with increase in the energy contributed by solar collector, this stated that less electrical energy required for drying process and regeneration process, respectively.

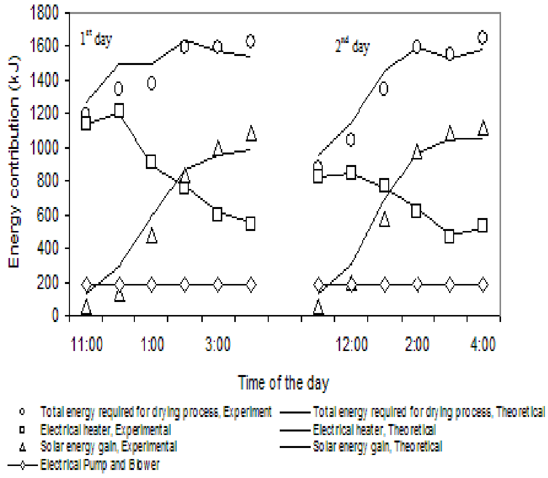

Fig. 6. Variations of energy contribution for drying process L with time.

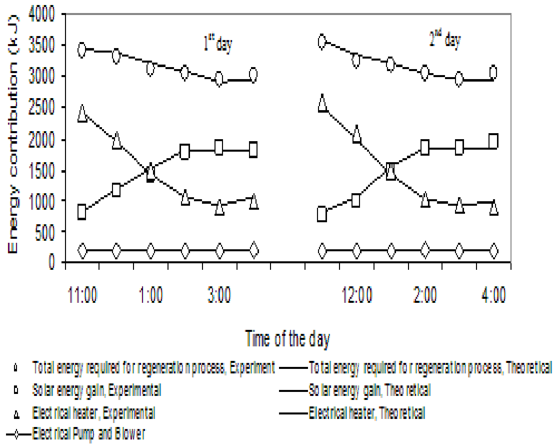

Fig. 7. Variations of energy contribution for regeneration process L with time.

Fig. 8. show variation of energy contributed by solar collector, auxiliary heater and blower and pump respectively to drying system for drying *Centella Asiatica* L from initial weigh of 3 kg to final weigh of 0.37 kg over drying time of about 12 hours at an air velocity is 3.25 m/s. It can be seen from this figure that total energy required of 47609 kJ, this energy contributed by solar collector, auxiliary heater and pump and blower of about 25315 kJ, 17829 kJ and 4464 kJ, respectively

Fig.9. show variation of solar fraction (SF) with time. The solar fraction depends on the instantaneous solar radiation. With an increase of solar radiation, the collector absorbs more energy, which is transferred to the water

flowing though the collector and, hence, increases the solar fraction. At the first day and second day a maximum solar fractions of about 70% and 68% was observed, respectively.

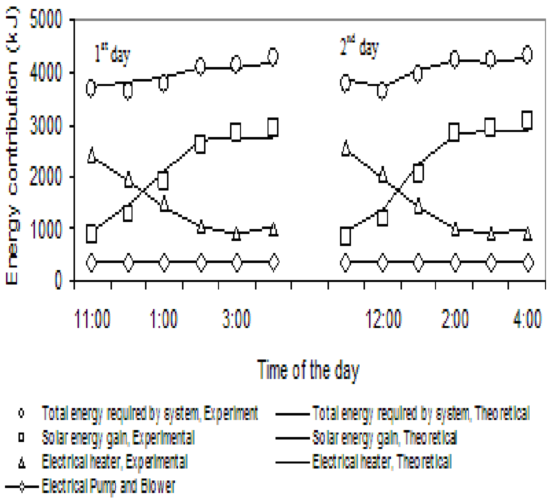

Fig.8. Variations of energy contribution for dehumidification system with time.

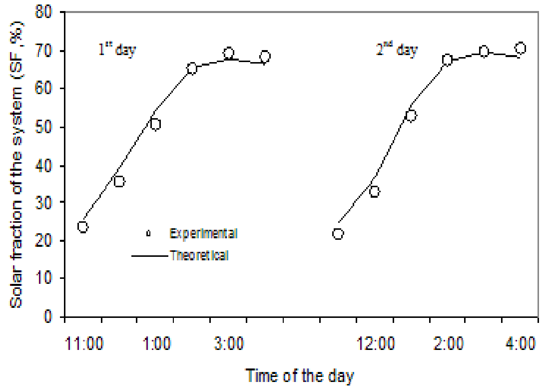

Fig.9. Variations of solar fraction of the drying system (SF) with time.

7. CONCLUSIONS

An experimental investigation was conducted to a solar assisted drying system consisting of solar collector, an energy storage tank, an auxiliary heater, two blowers, two adsorber columns, two water-air heat exchanger, two water circulating pumps, a drying chamber and other ancillary equipment. The solar collectors used were 60-evacuated heat pipes tube arranged in parallel with total area of 6 m^2. The area of absorber in tube each individual was 0.1 m^2, and distance between the tubes was 7.1 cm. The results found that the total energy required by drying system for drying *Centella Asiatica* L from initial weigh of 3 kg to final weigh of 0.37 kg over drying time of about 12 hours at an air velocity is 3.25 m/s was found 47609 kJ. This energy contributed by solar collector, auxiliary heater and pump and blower of about 25315 kJ, 17829 kJ and 4464 kJ, respectively. The maximum values of solar fraction (SF) was found 97%. The maximum value of temperature and the minimum value of relative humidity of drying air ware found 50^{o}C and 20%, respectively. Based on this results indicated that the solar drying system suitable for drying heat sensitive product like *Centella Asiatica* L because of drying process conducted at low air temperature and low relative humidity. Also the solar drying system may be developed because of contribution of energy from solar is very high.

Nomenclature

A_{Ct}	effective area collection of the solar panel (m^2)
C	specific heat (kJ/kg ^{o}K)
$\dot{G}$	mass flow rate (kg/s)
$\dot{m}_W$	water mass flow rate (kg/s)
Q	volumetric flow rate (m^3/s)
$\dot{Q}$	heat rate (W)
R_{et}	global thermal resistance for a panel towards the outside (^{o}C/W)
R_{dh}	dehumidification rate (kg/s)
R_{rg}	regeneration rate (kg/s)
W	mass of dry matter (kg)
$\dot{W}$	power (W)
X	moisture content dry basis of material (kg water/kg dry matter)
$\dot{X}_W$	drying rate (kg/s)

Subscripts

AD	adsorber column
CA	*Centella Asiatica* L
B	blower
DC	drying chamber

dh dehumidification
HT auxiliary air heater
i initial
P pump
rg regeneration
SG silica gel
t time (min)

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