Performance of a solar assisted dehumidification system for *Centella Asiatica* L

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Abstract

A solar assisted dehumidification 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 performance of this system has been investigated under the meteorological condition of Malaysia. A computer program was developed in MATLAB software to calculate the performance of the drying system. The performance indices considered to calculate the performance of the drying system are: Pick up efficiency (η_P), Solar Fraction (SF) and Coefficient of Performance (COP). The results indicated that the maximum values of the pick up efficiency (η_P), solar fraction (SF) and coefficient of performance (COP) was found 70%, 97% and 0.3, respectively with initial and final wet basis moisture content of *Centella Asiatica* L 88% and 15%, respectively at an air velocity is 3.25 m/s.

Keywords: Dehumidification; Drying of *Centella Asiatica* L; Performance of the drying system

1. Introduction

The used of medicinal herbs as alternatives to modern medications are safe and have virtually no side effects. Drying process is required for the preservation of the product. The main purpose of drying is to reduce the moisture content to such a level where spoilage due to the various reactions is minimized. Beside removal of water the quality of the dried product and drying time must be taken into consideration (Szentmarjay et al. 1996). In developing 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.

Centella Asiatica L is an ethnomedical plant used in different continents by diverse ancient cultures and tribal groups (Inamdar et al. 1996) 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 (Goh et al. 1995). These properties have been ascribed to the active ingredients in *Centella Asiatica* L: asiatic acid, asiaticoside, madecassic acid and madecassoside.

Malaysia as tropical country receives abundant solar radiation and having characterized by an average daily solar radiation of about 500-700W/m^2 (Sopian and Othman, 1991). This could be used for drying foods or other heat sensitive, biologically active products. Many type of solar hot air dryers have been developed effectively in Malaysia for drying of a variety of agricultural products. Since solar hot air driers are clearly not suitable for drying of foods or other heat sensitive, biologically active products, an alternative solar drier is proposed to do the job more effectively. Solar assisted dehumidification 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 performances of solar assisted dehumidification system. The performance of this drying system is indicated by Pick up efficiency (η_P), Solar Fraction (SF) and Coefficient of Performance (COP). A computer program developed in MATLAB software to calculate the performance of the drying system.

2. Description of solar assisted dehumidification system

A schematic diagram of the solar assisted dehumidification 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.

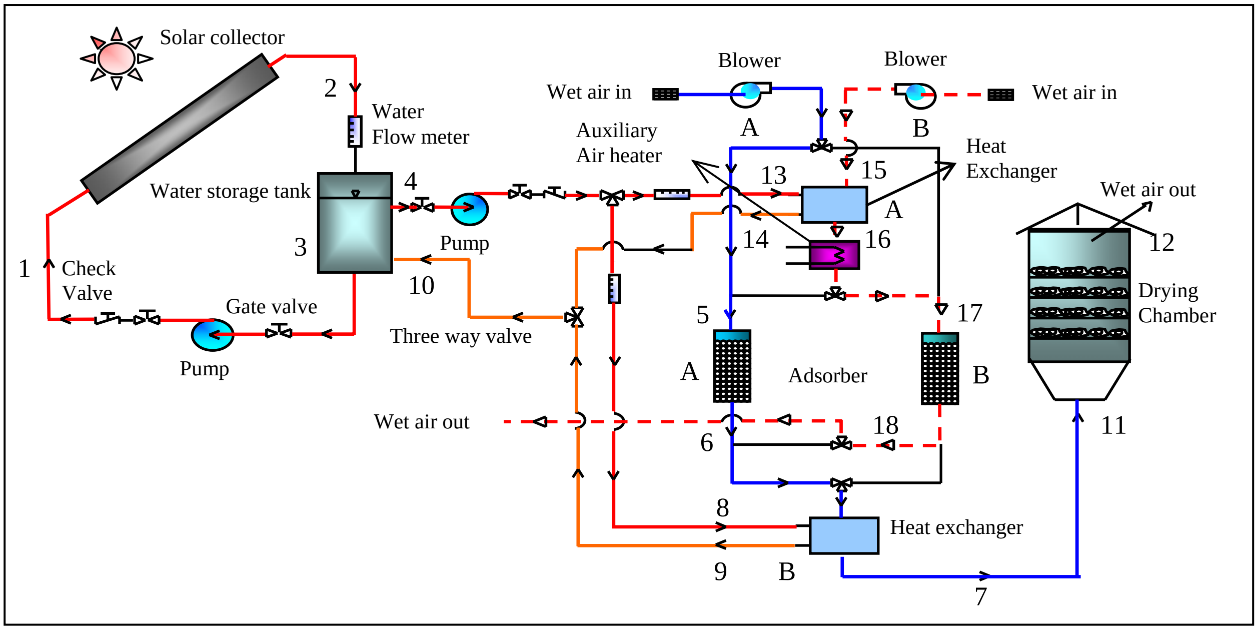

Figure1. Schematic diagram of the solar assisted dehumidification system

3. Theoretical background

The performance of a solar assisted dehumidification system depends on performance of each component. By using mass balance and energy balance equations for each components are obtained equations as follows:

a. The solar collector

Arcuri et. al (1995) 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

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

b. Adsorber columns

For dehumidification process

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

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

For regeneration process

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

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

c. Drying chamber

For drying process

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

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

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

d. Heat exchangers H_{E1} and H_{E2}

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

$$\dot{Q}_{HE1} = \dot{G}_a C_{Pa}(T_{16} - T_{15}) \qquad (11)$$

and

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

$$\dot{Q}_{HE2} = \dot{G}_a C_{Pa}(T_7 - T_6) \qquad (13)$$

e. Auxiliary air heater

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

f. Pump and Blower

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

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

g. Coeficient of performance of the drying system (COP)

The coefficient of performance of drying system is defined as the ratio the latent evaporation heat of the water content to be removed and the heat amount to be supplied to the dryer is given by:

$$COP = \frac{\dot{Q}_W}{\dot{Q}_{in}} \qquad (17)$$

$$\dot{Q}_{in} = \dot{Q}_U + \dot{Q}_{HT} + \dot{W}_P + \dot{W}_B \qquad (18)$$

$$\dot{Q}_U = \dot{Q}_{HE1} + \dot{Q}_{HE2} \qquad (19)$$

h. 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 (Duffie and Beckman, 1991):

$$SF = \frac{\dot{Q}_U}{\dot{Q}_L} \qquad (20)$$

i. Pick-up efficiency

This efficiency is more useful for evaluating the actual evaporation of moisture from the food (dried material) inside the drying chamber as follows (Tiris et. al (1995)):

$$\eta_P = \frac{\left(X_{Pi} - X_{Pt}\right) W_{dP}}{\dot{G}a\, \Delta t \left(Y_{DCas} - Y_{DCi}\right)} \qquad (21)$$

The values of Y_{DCas} and Y_{DCi} can be directly being obtained from Psychrometric chart.

3. Instrumentation

In order to evaluate the performance of 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.

4. Procedures

Fresh *Centella Asiatica* L was bought from the local market in Kajang, Selangor, Malaysia 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.

5. Results and discussions

The performance of a solar assisted dehumidification system was determined by drying of fresh *Centella Asiatica* L with initial weight and initial moisture content of about 3 kg and of 88% wet basis, respectively. The drying process 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. Its performances of the drying system as shown in Figure (2-7).

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%.

Fig.3. show variations of drying chamber inlet air temperature and relative humidity with time. As seen from figure the drying chamber inlet air temperature less than 50^{o}C and relative humidity less than 30%. This state that the 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.

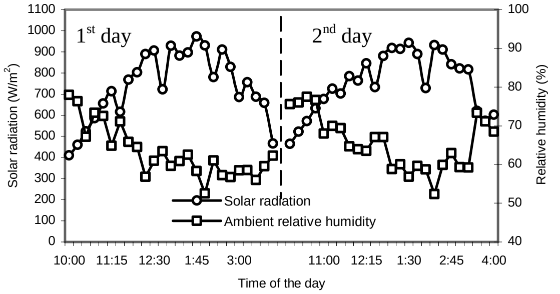

Fig.2. Variations of solar radiation and ambient relative humidity with time.

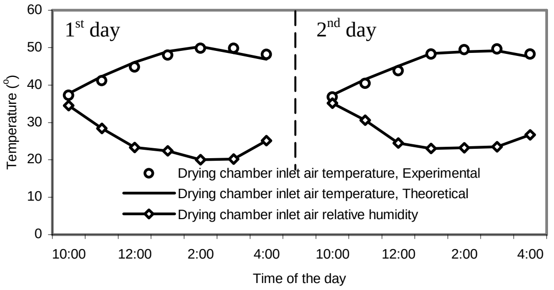

Fig.3. Variations of drying chamber inlet air temperature and relative humidity with time.

Fig.4. show variations moisture content pegaga leaf with time. The moisture content of the *Centella Asiatica* L 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.5. show variations pick up efficiency of drying system with time. The pick up efficiency depend on the evaporation of moisture from the products being dried inside the drying chamber. It can be seen from this figure that the pick up efficiency always declines during drying process, it because of the evaporation of moisture rate also declines. The pick up efficiency of drying system maximum values were observed at the first day and second day of about 97% and 29%, respectively.

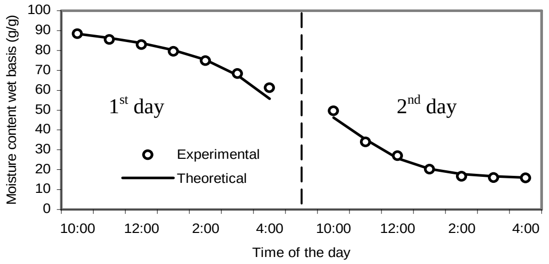

Fig.4. Variations of moisture content of *Centella Asiatica* L with time.

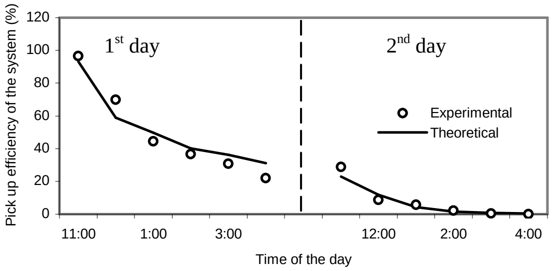

Fig.5. Variations of pick up efficiency of the system with time.

Fig.6. show variations performance of the drying system with time. The performances of the drying system maximum values were observed of about 0.3.

Fig.7. show variations of solar fraction (SF) with time. The solar fraction is contribution of solar energy to the drying system. It is 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.

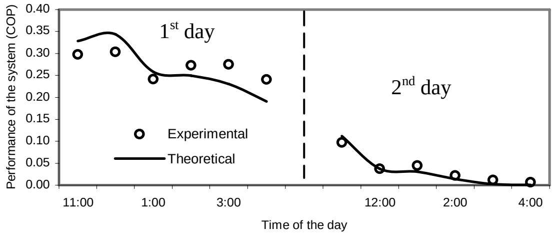

Fig.6. Variations of performance of the drying system (COP) with time.

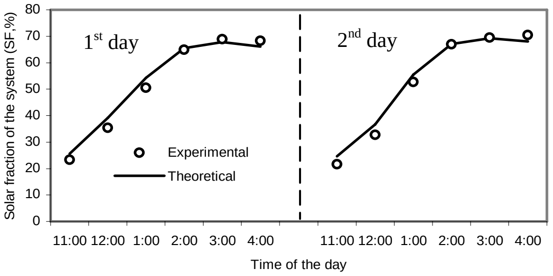

Fig.7. Variations of solar fraction of the drying system (SF) with time.

6. Conclusions

An experimental investigation was conducted to a solar assisted dehumidification 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 maximum values of the pick up efficiency (η_P), solar fraction (SF) and coefficient of performance (COP) was found 70%, 97% and 0.3, respectively with initial and final wet basis moisture content of *Centella Asiatica* L 88% and 15%, respectively at an air velocity is 3.25 m/s. 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 for pilot scale because of contribution of energy from solar is very high.

Nomenclature

A_{Ct}	effective area collection of the solar panel (m^2)
C_{Pa}	specific heat of dry air (kJ/kg ^{o}K)
C_{PW}	specific heat of moist air (kJ/kg ^{o}K)
$\dot{G}_a$	mass flow rate of dry air (kg/s)
$\dot{G}_W$	mass flow rate of water (kg/s)
$\dot{m}_{WC}$	water mass flow rate through collector (kg/s)
$\dot{m}_{WHE}$	water mass flow rate through heat exchanger (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)
Y_{as}	adiabatic saturation humidity of air entering the drying chamber (kg water/kg dry air)

Subscripts

AD	adsorber column
CA	*centella asiatica*
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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