Performance Analysis of an Indirect Solar Air Dryer by Evaluating Evaporative Capacity

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Abstract— Aim of this paper is to study an effect of evaporative capacity by evaluating a performance of solar air heater and dryer. This is also a performance indicator of the solar collector like a widely-used ‘‘collector efficiency’’. The comparison of variation in evaporative capacity with other properties and thermal efficiency are analyzed. The effect of meteorological conditions on performance of solar dryer can be found. Importance of the evaporative capacity and methods for determining the evaporative capacities are presented.

Key words: Solar Dryer, Evaporative Capacity, Chili, Water Activity, Humidity, Solar Air Heater

I. INTRODUCTION

Many authors have been analyzed the performance of solar air heater by defining the ‘collector efficiency’. They have presented both theoretically and experimentally the optimization of collector’s thermal efficiency of solar air heater which is given by.

$$\eta c = \frac{\dot{m}a\ Cp(t2-t1)}{Ac\ G} \qquad (1)$$

Solar air heater is a component of a solar drying system (Fig. 1). The study of solar air heater with solar drying chamber is done. Experimentation on solar air heater operating for chili drying is done at Nagpur (Latitude 21.1458004N, Longitude 79.0881546E) in September at 10 am. Meteorological conditions were as, t1 =26°C, ϕ1 =73%, C =3 m / s and G =410 W/ m2, as taken from an example treated by Jannot (1994). By using Whillier-Bliss formula (Duffie and Beckman, 1980). The thermal efficiency of a single glass covered solar air heater (Fig. 1) is calculated by considering two specified air flow rates. The area of collector is 0.72 m² (2’x 4’). The collector outlet air conditions would be as follows: (a) t1 =34.7°C and ϕ1 =51.6%; (b) t2 = 32°C and ϕ2=60.5%. The results were found (a) The collector efficiency for an air flow rate (0.014 Kg/sm²) is ηc =28%, and (b) for an air flow rate (0.027 Kg/sm²) is ηc =36%.

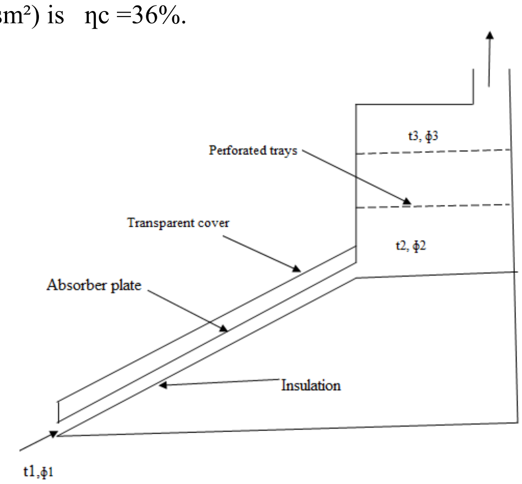

Fig. 1: Schematic view of the solar dryer

The initial average moisture content and water activity of fresh chili were 85.15% and 0.99, respectively. The average moisture contents of all dried chili were 11% wet basis and water activities varied between 0.51 and 0.68. The moisture content of chili is very important because it is strongly correlated with the stability of ascorbic acid and pigment as well as any hygiene problems (Kim *et al*., 1982). Carbonell *et al.* (1986), Lee *et al.* (1992), and Kanner *et al*. (1977) all reported that the moisture content of dried chili ranged from 10 to 14% which could retard colour loss. Moisture content lower than 8% could accelerate pigment destruction. Wall and Bosland (1993) reported that final moisture content at 8% is ideal. Moisture content above 11% allows mould to grow and moisture content below 4% causes an excessive colour loss. However, chili generally needs to be dried to a moisture content of below 13% in order to prevent potential aflatoxin production (Pitt and Hocking, 1997).

The chili to be sufficiently dried, their water content X must reach 11% wet basis, which corresponds to a water activity in the product of aw=0.51, according to Fournier and Guinebault (1995), who define the water activity (aw) as the relative humidity of air in equilibrium with the material at the same temperature. Thus chili that have X = 17% wet basis (corresponding to aw=0.6) need to be further dried. It appears that in case (b) the collector outlet air cannot dry chili having X=17% wet basis, since ϕ2 =60.5% and ϕ1>100aw, whereas in case (a), drying is still possible, since ϕ1 =51.6% and ϕ1 < 100aw. Nevertheless, the comparison of the thermal efficiencies in case (a) and (b) would lead us to choose an air flow rate to collector area ratio of 0.027 kg/ s m², whereas taking into account the particular use that is made with the heated air will lead us to choose a ratio of 0.027 kg/ s m². This study leads us to consider a evaporative capacity as a performance parameter to used when a solar air heater is designed for food drying.

A. *Evaporative Capacity of Solar Air Heater*

Ambient temperature air is enters in solar collector which gets heated and passes through the drier attached in series represented by line AB on the psychometric chart (Fig. 2). Air at point ‘A’ enters the collector where it is heated at a constant pressure. Then, at point ‘B’ it enters the drying enclosure, where it is isenthalpic- ally humidified before leaving the drier at point ‘C’. If aw is the water activity of food in the drier, the maximum rate at which water can be extracted by the air flow from the product is

$$E = \dot{m}a\ (w3 - w1) \qquad (2)$$

Where ṁa is the dry air flow rate, w1 is the ambient absolute humidity, and w3 is the drier outlet absolute humidity when air leaves the drier in equilibrium with the product, i.e., when ϕ = 100 aw.

E is called the evaporative capacity of the solar air heater, and by application of the formula of Jannot (1993), its calculation procedure is as follows:

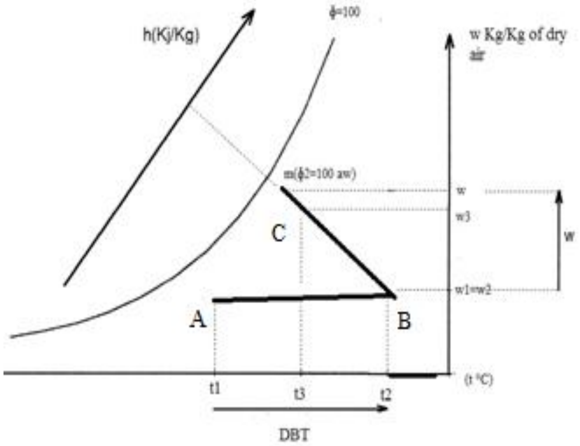

Fig. 2: Representation of drying process on psychrometric chart.

Atmospheric conditions (t1, ϕ1, C, G) are presumed to be Known. The partial vapor pressure in air is first calculated as:

$$\mathrm{Pv} = \frac{\phi 1}{100} Ps(t1) \qquad (3)$$

With

$$log10[Ps(t1)] = 708.2 - \frac{372544}{t1} - 516.56 log^{10}(t1) \quad (4)$$

The thermal efficiency (ηc) of the solar collector is calculated by the Hottel-Whillier-Bliss equation (Duffie and Beckman, 1980; Sfeir and Guar- racino, 1981). The collector outlet air temperature t2 is then calculated from:

$$t2 = t1 + \frac{Ac\ G\ \eta c}{ma\ Cp} \qquad (5)$$

The corresponding wet bulb temperature tw2 is determined by solving the following equation:

$$Pv1 = Ps(tw2) - \frac{Cp(t2-tw2)[P1-Ps(tw2)]}{0.622Lu(tw2)} \qquad (6)$$

With

$$\mathrm{Lv(tw2)} = 2.5018 \times 10^{6} - 2.378 \times 10^{3}\ \mathrm{tw2\ J/K} \quad (7)$$

Atmospheric air humidity is then determined from:

$$\mathrm{w1} = 0.622 \frac{\mathrm{Pv1}}{\mathrm{P1-Pv1}} \qquad (8)$$

And then the drier outlet temperature t3 is determined by solving the following equation:

$$\mathrm{awPs(t2)} = \mathrm{Ps(tw3)} - \frac{\mathrm{Cp\ (t3-tw3)[P1-Ps(tw3)]}}{\mathrm{0.622Lv(tw3)}} \quad (9)$$

In which it is assumed that tw3 = tw2 . The drier outlet air humidity is then obtained from:

$$\mathrm{w3} = 0.622 \frac{\mathrm{Pv3}}{\mathrm{P1-Pv3}} \qquad (10)$$

With

$$\mathrm{Pv3} = \mathrm{awPs(t3)} \qquad (11)$$

Finally the evaporative capacity

$$\mathrm{E} = \frac{\mathrm{ma}}{1+\mathrm{w1}}(\mathrm{w3-w2}) \qquad (12)$$

Us this above formulae to different conditions (a) and (b) Of the previously-discussed example (with a collector area of 0.72 m²) gives the following results for cases (a) and (b) respectively: (a) E =1.422 〚10〛^(-4) kg/s; (b) E < 0.

The collector's thermal efficiencies gives the performance of collector and from values of Evaporative capacity (E) would lead us to choose an air flow rate to collector area ratio of 0.027 kg/ s m², which enables the drying to go on. Thus the evaporative capacity seems to be a better criterion to evaluate the performance of solar air heaters used in combination with food dryers. Fig. 3 presents the evolution of ηc and E for different air flow rate to collector area ratio, under the meteorological conditions prevailing in September at 10 am in Nagpur (MS), for drying a product having aw = 0.6. It can be deduced from Fig. 3 that the optimal air flow rate to collector area ratio is 0.14 kg/ s m² under the assumed conditions.

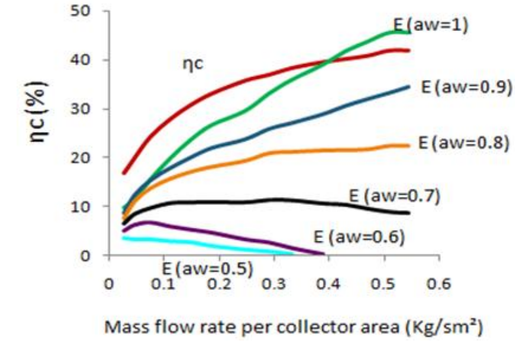

Fig. 3: Collector efficiency and Evaporative capacity with Mass flow rate of air per collector area.

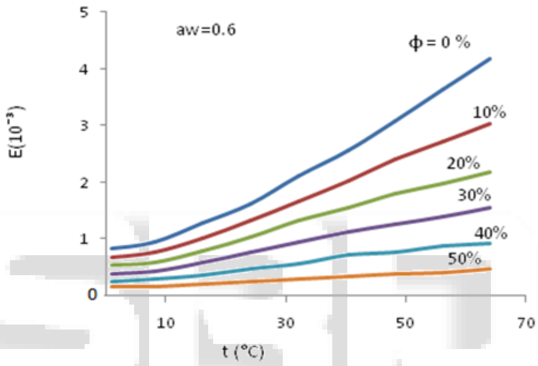

Fig. 4: Evaporative capacity with relative humidity and DBT

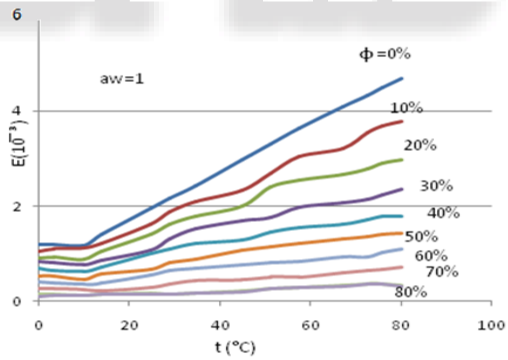

Fig. 5: Graph for determination of the evaporative capacity with respective DBT and Relative humidity

II. RESULT

To create a graph which are based on a specified air flow rate of 0.027 kg/ s m² (corresponding to 1000 m3/ h), the previously defined formulae by various authors has been used. These graph gives a reference evaporative capacity, denoted E, and it is given for products having various values of water activity aw (Graph corresponds to a fixed value of aw) as a function of the ambient air temperature and humidity (absolute or relative). Fig.4 and fig.5 are also shows an effect of evaporative capacity with relative humidity and dry bulb temperature. These graph may be used to select the best air flow rate for a solar air heater at a giving time of the drying process – i.e. one that maximizes the drying evaporative capacity – by the following procedure:

1) Calculate the collector outlet air conditions by the Hottel–Whillier-Bliss equation, or equivalent;
2) Determine E by using graph with taking the reference of water activity.
3) Calculate E for the actual air flow rate by using

$$E1 = \frac{E.q}{0.278} \tag{13}$$

By using these graphs the effect of meteorological conditions on performance of solar dryer can be found.

Very important differences in the corresponding values of E are to be observed. They show the important influence that ambient air temperature and humidity have on the performance of a solar drier. This influence is not properly taken into account when one considers only the collector efficiency.

III. CONCLUSION

A different performance parameter has been studied for solar air heaters used in combination with food dryers. This criterion can be a useful tool to determine the performance of solar dryer as a comparisons with collector efficiency. The effect of meteorological conditions on performance of solar dryer can be found. It may also be helpful for optimizing the best flow rate in a solar drier selecting, at any given time that has variable air flow, depending on the state of the food.

NOMENCLATURE

A area (m^2)
aw water activity defined in Introduction
Cp specific heat of air (J/ kg °C)
ϕ relative humidity of air (%)
E evaporative capacity (kg/ s)
G solar irradiance (W/ m)
Lv latent heat of vaporization of water (J/ kg)
ṁ mass flow rate of air (kg/ s m^2)
P atmospheric pressure (Pa)
Pv partial water vapor pressure
q Volume flow rate of air (m^3/s)
t temperature (°C)
tw wet bulb temperature (°C)
C wind velocity (m/s)
w absolute humidity (kg/kg of dry air)
X wet basis water content of food (%)
Ƞc thermal efficiency of collector (%)

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