Performance Evaluation of a Forced Convection Solar Drier with Evacuated Tube Collector for Drying Amla

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***Abstract* — A forced convection solar drier is designed with evacuated tube collector and a blower. The performance of the designed drier is evaluated by carrying drying experiments at Thanjavur District, Tamilnadu, India with amla. Solar drying of amla is carried at different air velocity flow rates – 4m/s, 4.25m/s and 4.5m/s and is compared with natural sun drying. The temperature of the drying chamber ranges from 53ºC to 82ºC while the ambient temperature ranges from 29ºC to 32ºC. The efficiency of the designed drier varies from 38.61% to 43.7% where as the efficiency of sun drying varies from 12.5% to 14.15%. It is observed that the efficiency of the drier increases with increase in air velocity flow rates. Initial moisture content of amla ranges between 83.6% and 84.3% and the equilibrium moisture content ranges between 0.1% and 0.6%. Solar drying takes 5 to 7 hours to reach safe moisture content where as sun drying takes 13 to15 hours. Also the quality of solar dried amla is better in terms of colour, odour, flavour and appearance than the sun dried amla. The observed result of the present work shows that the proposed solar drier is good for drying amla in this region.**

Keyword-Forced convection, Evacuated tube collector, Solar drier, Amla, Efficiency, Moisture content, Quality

I. INTRODUCTION

Amla (*Pyllanthus emblilica*), the Indian gooseberry, is the richest source of vitamin C (Ascorbic acid) among all the fruits [1]. Every 100g of amla contains nearly 700 – 750 mg of vitamin C. Amla is also rich in vitamins and minerals like phosphorous, iron, calcium, carotene and vitamin B complex [2]. The spherical, six lobed, light greenish yellow amla fruit is sour, bitter and astringent to taste and is fibrous. It is found to have strong antioxidant properties. It is highly nutritive and has plenty of medicinal properties that made it more popular. Many Ayurvedic and Unani preparation use amla as a major constituent as it rejuvenates all the organ systems of the body and promotes health and wellness. Amla helps in curing a number of ailments like fever, anemia, indigestion, constipation, liver disorder, piles, heart complaints and urinary problems. It is most preferred in the treatment of skin, hair loss, diabetes etc. It has got antibacterial property and anti-ageing property. It is available in autumn season. Indigenous to India, it is grown almost in all tropical and subtropical regions. It is reported that about 500 tons of amla is exported from India under the category of Ayurvedic and Unani herbs because of its medicinal, nutritional and culinary use [3].

Due to its astringent taste it is not consumed freely in fresh. To consume it easily and to make it available throughout the year, it needs processing. Several value added products from amla have been reported. A comparative study on the effect of different drying methods such as sun drying, tunnel drying, spray drying, freeze drying and vacuum drying of amla done by Poonam Mishra et al shows lowest concentration of ascorbic acid in sun drying [4]. A study has been carried by Pragati et al on the nutritional composition of dehydrated aonla fruit [5]. Drying plays a major role in which the free water molecules are removed leaving the essential bound water molecules. This helps in preserving amla over a long period as it is free from fungal and microbial attack.

The ancient method used to preserve food is natural sun drying. But natural sun drying has many disadvantages such as uncontrolled drying, contamination by birds, insects and dust, climatic adversities etc. The quality of the product is found to be less and cannot be exported. It also requires more labour and the process is found to be slow. Amla if dried in shade can retain much of iron and vitamin C and other original nutrients.

Different types of driers have been reported. Mohanraj et al has reported that the drier with heat storage material enables to maintain consistent air temperature inside the drier [6]. Though mechanical driers have overcome most of the above mentioned disadvantages in natural sun drying, it requires electricity and is quiet costlier. Moreover, many rural areas do not have uninterrupted power supply. Solar driers have become more popular among farmers. These solar driers mostly make use of flat plate collectors to collect radiation from sun. Thin layer solar drying of Cuminum Cyminum grains by means of solar cabinet dryer using flat plate collector reported by Mehdi Moradi et al shows that natural convection solar drying air flow rate in mixed mode is selected as the best method for drying Cuminum [7].

But it has been reported that the efficiency of evacuated tube collector is very high as compared to the efficiency of flat plate collectors. However, only few experimental studies have been reported on solar evacuated tube driers [8]-[10].

So an attempt has been made to design and construct a novel solar dryer with evacuated tube collectors and study its performance on amla in Thanjavur district, Tamilnadu, India. The solar dried amla is compared with sun dried amla. The advantages of the newly designed solar drier are quick drying, good quality, controlled pollution free drying and high efficiency.

II. MATERIAL AND METHOD

A. Design Calculation

The size of the drier is selected according to the design parameter which is given as [11],

$$R = SA / V \text{ --------------------(1)}$$

Where SA is the surface area of the glazing of the collector and V is the volume of the drying chamber. If the ratio is equal to or greater than three then the design of the drier is said to be good. The evacuated tube collector is tubular and is capable of trapping solar radiation throughout the day by placing the collector at optimum collector slope (Latitude of the location + 15º) [12]. The measurement of the design parameters of the designed solar drier is given in table1.

TABLE 1

THE MEASUREMENT OF THE DESIGN PARAMETERS OF THE DESIGNED SOLAR DRIER

S. No.	Design Parameter of the Solar Drying System	Measurement
1	Surface area of the evacuated tube collector	$0.4086m^2$
2	Volume of the Drying Chamber	$0.091125m^3$
3	SA / V Ratio	4.48
4	Latitude of Thanjavur	10º45'N
5	Collector slope	25º45'

B. Experimental Set-up

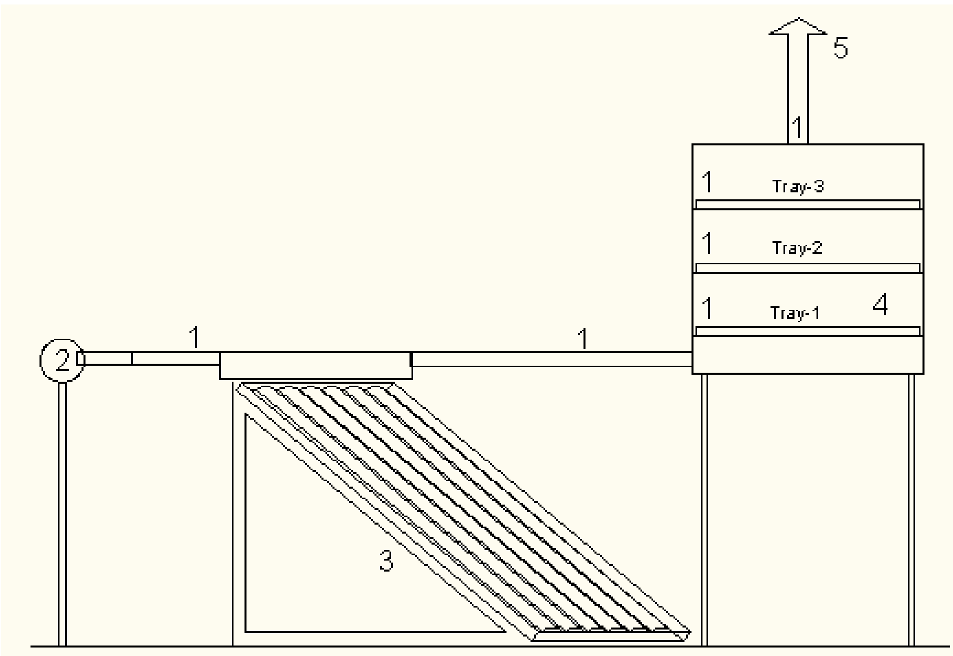

Fig. 1 Schematic diagram of the experimental set-up (1, temperature sensor; 2, blower; 3, evacuated tube collector; 4, drying chamber; 5, chimney)

This novel solar drier is mainly constructed with four essential features namely, the drying chamber, the evacuated tube collector, the blower and the chimney. Figure 1 shows the section of the solar drier. Based on the quantity of the product to be dried, the air flow rate, the temperature required to dry the product and the design parameter mentioned in eqn.1, the drying chamber is designed. The drying chamber of size 18' x 18' x 18' is made of stainless steel sheets of thickness 25mm and insulated on all sides with rock wool slab of thickness 50mm compressed to 40mm to prevent loss of heat. It consists of three aluminium perforated trays to place the material to be dried.

It consists of six evacuated tube collectors with a copper header for heat exchange. The twin glass evacuated tube collector is made of borosilicate of 1.6mm thickness and the gap between the glass tubes is evacuated. The inner tube of the collector is coated with a three layer magnetron sputter coating (SS – Al N/Cu). Heat loss due to convection, conduction and radiation is thus minimized and it can withstand high temperature due to this technology. The length, inner diameter and outer diameter of each tube are found to be1500mm, 37mm and 47mm respectively. The collector is placed along N-S direction, facing south so as to track maximum solar radiation throughout the day. This collector which is used as air heater is connected to the drying chamber with the help of EPDM (Ethylene Propylene Diene Monomer) rubber hose.

To blow air into the collector, a blower motor of 0.335kW, 1300rpm with a regulator to control the rate of flow of air is attached at the inlet of the collector. Regulator in the blower motor is used to vary air velocity flow rates.

A chimney of height 100cm made of SWG (Standard Wire Gauge) Gl (Galvanized) sheet is used at the top of the chamber to remove the outgoing moist air. Chimney increases the air flow rate inside the chamber under the convective principle of hot air rising up.

C. Measuring Instruments and Devices

A digital anemometer (MASTECH MS 6252B) is used to measure the relative humidity, ambient temperature and wind velocity. A solar power meter (TES – 1333) is used to measure the hourly solar insolation and the samples are weighed using a digital electronic balance (D-Sonic Digital scale: $\pm$ 0.1g accuracy).Temperatures are measured at different points. LM35 sensor with associated components is used for the measurement of temperature of the lower, middle, upper tray inside the chamber and temperature of the chimney.

D. Experimental procedure

Amla is cut into six pieces along the vertical furrows. The initial moisture content of amla is measured by placing 200g amla pieces in hot air oven at a temperature of 105ºC for 24 hours. Amla pieces are uniformly spread in 3 trays and are kept inside the chamber for solar drying. Simultaneously, amla is spread in a tray and is kept for natural sun drying. In the newly designed solar drier, air is blown into the evacuated tube collector with the help of the blower. Due to the solar radiation falling on the collector, the collector gets heated up and transfers heat to the air flowing through the collector. This hot air enters the drying chamber where amla is loaded in trays. The moving hot air evaporates the water content (moisture) of the amla under the basic mechanism of removal of moisture from the surface of the product to the surrounding followed by the removal of moisture from inside the product to the surface [13]. The readings are taken on hourly basis from 9.00am to 5.00pm until amla attained equilibrium moisture content. The regulator in the blower motor is adjusted and the air velocity flow rate is kept at 4m/s, 4.25m/s and 4.5m/s. The entire experiment is repeated to study the performance of amla at different air velocity flow rates.

E. Data Analysis

1) Determination of Moisture Loss

Moisture loss of amla is calculated every hour using the formula [13],

$$M_L = m_i - m_f \quad \text{------------ (2)}$$

Where m_i = initial mass of the sample

m_f = final mass of the sample

2) Determination of Moisture Content

The % of moisture content on wet basis (M_{wb}) is found using the formula [13],

$$\% \, M_{wb} = \frac{mi - mf}{mi} \times 100 \quad \text{------------ (3)}$$

Where m_i = initial mass of the sample

m_f = final mass of the sample

3) Determination of Drying Rate

The drying rate of amla is determined using the formula [14],

$$DR = \frac{\Delta M}{\Delta t} \quad \text{------------ (4)}$$

Where ΔM = loss of the mass of the crop

Δt = interval of time

4) Determination of Drier Efficiency

The efficiency of the solar drier is given as [11], [13]

$$\eta_d = \frac{ML}{IAt} \quad \text{------------ (5)}$$

Where M = mass of the water evaporated from the crop

L = latent heat of vaporization of water

I = solar insolation

t = time of drying

A = effective area of the collector.

III. RESULT AND DISCUSSION

Solar insolation, wind velocity, ambient temperature, ambient relative humidity, temperature and relative humidity inside the chamber are measured on hourly basis while drying amla in the designed drier.

TABLE II

AVERAGE SOLAR INSOLATION, WIND VELOCITY, AMBIENT TEMPERATURE AND RH, TEMPERATURE AND RH INSIDE THE CHAMBER

Time	Solar Insolation W/m^2	Wind velocity m/s	Ambient		Chamber	
			Temp.	% RH	Temp.	% RH
9.00	508	1.04	31	59	32	67.5
10.00	726	0.77	29	62	53	67.5
11.00	990	0.59	30	58	65	63
12.00	996	0.84	31	54	75	53.2
13.00	1144	1.00	32	46	81	50.2
14.00	1043	1.48	32	44	82	41.5
15.00	834	0.62	32	44	77	51.2
16.00	621	0.52	31	51	69	49
17.00	175	0.78	30	52	61	47

From table2, it is observed that average ambient temperature varies from 29ºC to 32ºC where as the temperature of the chamber varies from 53ºC to 82ºC. By comparing the ambient temperature and the temperature inside the chamber it is evident that the efficiency of the designed drier is more than the natural sun drying. The solar insolation ranges from 175W/m^2 minimum to 1144W/m^2 maximum. It is observed that the solar insolation is higher during mid-noon and as a result the temperature of the chamber is higher during this period. The relative humidity of the chamber is found to be higher than the ambient relative humidity as the air in the chamber gains moisture from amla.

The efficiency of the solar drier varied from 38.61% to 43.7% for amla under full load condition at different air velocity flow rates while the efficiency of the sun drying varied from 12.5% to 14.15% during these days. From Fig.2 it is observed that the efficiency of the drier increases with increase in air velocity flow rates.

Variation of moisture content (%wb) with respect to drying time for different air velocity flow rates is shown in Fig. 3. The initial moisture content varied from 83.6% to 84.3% where as the final moisture content varied from 0.1% to 0.6%. The drying time taken by amla to reach equilibrium moisture content varied from 5hours to 7hours for different air velocity flow rates in the designed drier. But in natural sun drying, the time taken by amla to reach equilibrium moisture content varied from 13hours to 15hours. It is observed that drying time gets reduced as air velocity flow rate increases.

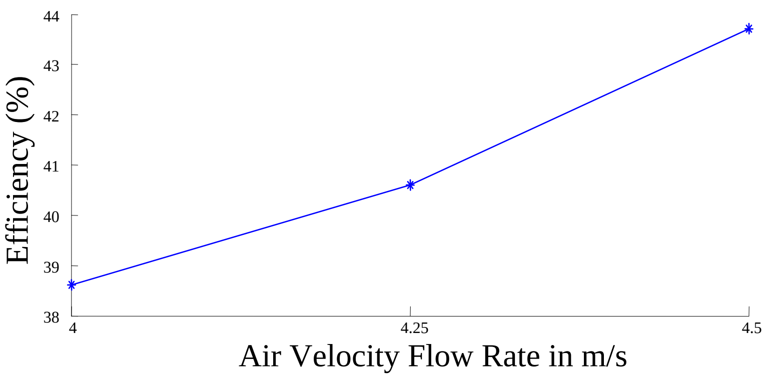

Fig. 2: Thermal efficiency of the designed solar drier for amla at different air velocity flow rates

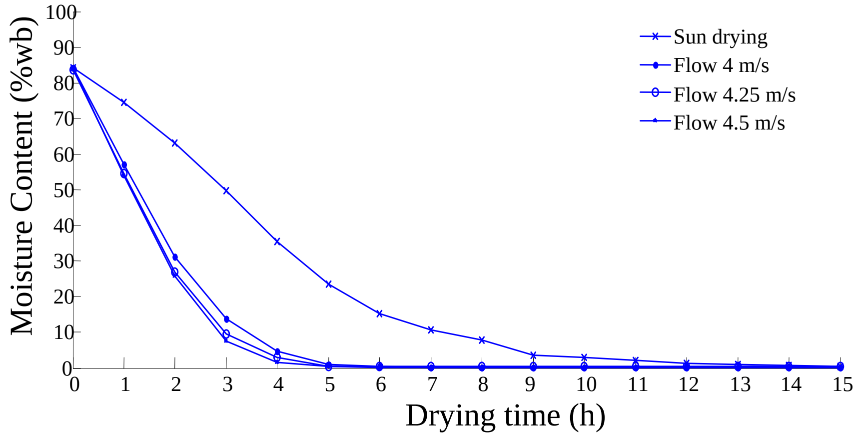

Fig. 3: Variation of Moisture content (%wb) Vs Drying time for sun drying and solar drying at different air velocity flow rates

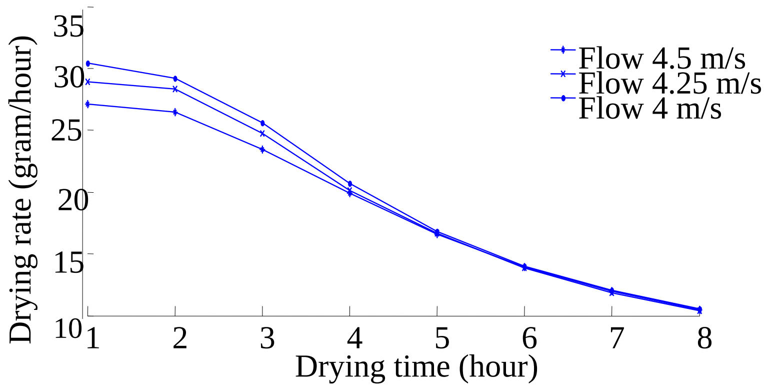

Fig. 4: Variation of Drying rate Vs Drying time for solar drying at different air velocity flow rates

Variation of drying rate with respect to drying time is shown in Fig.4. Initially, the rate of drying is more and is found to be decreasing as time increases. This is because of the removal of moisture from the surface first followed by the movement of moisture from internal part of the product to its surface. Also it is found that the drying rate is more for higher air velocity flow rates. The average drying time required for amla in the designed drier is found to be 6 hours to reach safe moisture content.

The quality of the solar dried amla is higher than the sun dried amla as the natural colour and the appearance are maintained more in solar dried amla. Also the flavour and odour of the solar dried amla is more satisfactory than the sun dried amla. The labour required in solar drying is lesser and the drying rate is faster. Solar dried amla is well protected against rain, rodents and insects. It is also free from dust and contaminations. Above all, it is capable of meeting high standards to export amla.

IV. CONCLUSION

The newly designed solar drier with evacuated tube collectors is easy to construct. This drier generates higher air temperature inside the chamber and promotes drying rate thereby reducing the drying period. The time taken by the solar drier to reach safe moisture content is less than half the time required in natural sun drying. As the solar drier makes use of evacuated tube collector it can perform better even during cloudy days and winter season. The drying process can also be controlled in the designed drier which cannot be done in natural sun drying. Further, the drying time is reduced as the air velocity flow rate is increased. The quality of the solar dried amla is high in terms of colour, flavor and appearance as compared to sun dried amla. Amla dried in the designed drier suits better for export due to its high quality standard. The drier is also pollution free. This drier can be used to dry any agricultural product. So, it is evident that solar driers with evacuated tube collectors are better than any other driers.

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