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Design of Solar Dryer Assisted with Reflector for Drying of Medicinal Crops

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A B S T R A C T

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K e y w o r d s

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Preservation of fruits, vegetables, and food are essential for keeping them for a long time without further deterioration in the quality of the product. Solar drying has been used since time immemorial to dry plants, seeds, fruits, meat, fish, wood, and other agricultural, forest products. The aim of the dryer is mainly for the welfare of the marginalized and poor farmers those who can't afford hi-tech facilities and equipment's to preserve their agricultural products. Drying of Safed Musli (*Chlorophypum boribilianum*) in open sun drying require more time and affected its quality. In order to maintain quality and to increase sufficient temperature in the drying chamber during winter, morning and evening hours, a solar dryer assisted with reflector was designed. The main principle of this domestic solar dryer is based on greenhouse effect where the solar heat is trapped inside the drying chamber and thus increases the temperature in addition to reflected direct radiations. A domestic dryer assisted with reflector was designed and developed for drying of safed musli in batch. The dryer was fabricated as per design specification and its performance was evaluated in the Department of Unconventional Energy Sources and Electrical Engineering, Dr. PDKV, Akola. The paper deals with design, material and experimental techniques used for studying the performance evaluation of a domestic solar dryer assisted with reflector for drying of safed musli. At no load test without reflector the maximum temperature of 51.24°C was achieved in the afternoon and average temperature in the solar dryer was found to be 41.02°C at corresponding ambient temperature of 21.7°C, solar radiation 430.86 W/m^2, relative humidity 23.26%, in the morning of December 2014. The maximum temperature recorded in December 2014 was 58.46 at 13.30 h. The average temperature of domestic dryer was found to be 44.22°C at ambient temperature of 31.3°C, relative humidity 31.7%, solar radiation 553.80 W/m^2 during the month of March 2015.The average moisture content of Safed Musli samples placed in T1, T2 and T3 trays reduced from 651.5 to 4.5, 654.7 to 7.7 and 656 to 14.5 % (db) in 8 h, respectively in domestic solar dyer integrated with reflector. The average moisture content of Safed Muslisample reduced from 613 to 7.8 % (db) in 12 h. Average drying rate was found to be 0.5526, 0.54103 and 0.53455 gm/100gm bdm min, respectively. The average drying efficiency of Safed Musli samples dried in domestic solar dryer with reflector was found to be 22.92 % respectively.

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Introduction

Preservation of fruits, vegetables, and food are essential for keeping them for a long time without further deterioration in the quality of the product. Drying is a simple process of moisture removal from a product in order to reach the desired moisture content and is an

energy intensive operation. Enormous amount of energy from the sun falls on the earth's surface. All the energy stored in the earth's reserve of coal, oil, and natural gas is matched by the energy from just twenty (20) days of sunshine. The energy in sunlight at noon in a cloudless day that falls on earth's surface is about 1000 kw/m^2 (Gutti *et al*., 2012).

During drying, it is necessary to remove free moisture from the surface and also from the interior of the material. When hot air is blown over the product, heat is transferred to its surface and the latent heat of vaporization causes water to evaporate. Water vapour diffuses through a boundary film of air. This creates a region of lower vapour pressure at the surface of the grain and a water vapour gradient is established from the most interior part of the grain to the dry air. The gradient provides the driving force for removal of water from the food.

The main principle of this domestic solar dryer is based on greenhouse effect where the solar heat is trapped inside the drying chamber and thus increases the temperature. Drying of agricultural materials such as grains is a non-linear process with long time delay and considerable complexity. Therefore, it is very difficult to establish a precise mathematical model for grain drying control (Cao and Wang, 2002). Although some mathematical models of drying process itself have been established, their structures are often too complex to be used for control model and hence effective control is very difficult to be realized (Marchant, 1985; Courtois *et al*., 1985).

Cyclone type thin-layer dryer for drying agricultural materials developed by Apikar (2002) was introduced in the literature for drying study of some vegetables and fruits including potato, red pepper, apple, strawberry, and pumpkin.

Materials and Methods

The material and experimental techniques used for studying the performance of a domestic solar dryer assisted with reflector for drying of Safed Musli was discussed. The present research was initiated with the design and development of a domestic solar dryer assisted with reflector (Figure 1).

Design and fabrication of domestic solar dryer assisted with reflector

The domestic solar dryer assisted with reflector was designed for drying Safed Musli. The stepwise procedure for design and development of domestic solar dryer assisted with reflector has been discussed as follows. Domestic solar dryer assisted with reflector consisted of following components:

1. A trapezoidal shaped drying chamber
2. A Reflector
3. A Chimney

Design considerations of domestic solar dryer assisted with reflector

The initial design and assumptions made for domestic solar dryer are given in table 1.

The design calculations for development of domestic solar dryer

The stepwise design calculations of domestic solar dryer for drying of Safed Musli are given as below.

1. Total quantity of water in the product, M$_{tw}$

$$M_{tw} = W \times \frac{M_i}{100}$$

Where,

M$_{tw}$ - Total quantity of water in product, kg

W - Weight of the product, kg
M_i - Initial moisture content of product in % (wb)

$$\therefore M_{tw} = 6 \times \frac{86}{100}$$

= 5.16 kg

2. Bone dry weight of material, W_{bd}

$$W_{bd} = W_g \times \left[1 - \left(\frac{M_i}{100}\right)\right]$$

Where,

W_{bd} - Bone dry weight of material, kg
W_g - Quantity of product, kg
M_i - Initial moisture content of product in % (wb)

$$\therefore W_{bd} = 6 \times \left[1 - \left(\frac{86}{100}\right)\right]$$

= 0.84 kg

Hence, final weight of product at 12% moisture content

$$\therefore W_f = W_{bd} \left[\frac{100}{100-12}\right]$$

= 0.95 kg

3. Quantity of water to be evaporated, M_w

$$M_w = \frac{(M_i - M_f)}{(100 - M_f)} \times W$$

Where,

M_w - Quantity of water evaporated from product, kg
W - Weight of the product, kg
M_i - Initial moisture content of product in % (wb)
M_f - Final moisture content of the product in

% (wb)

$$\therefore M_w = \frac{(86 - 12)}{(100 - 12)} \times 10$$

= 5.04 kg

4. Drying rate, m_w

The drying time during which the drying takes place, i. e. the effective sunshine hours was considered as 9:00 to 17:00 h. It was observed by most of the scientists that optimum drying time for Safed Musli ranged from 16 to 18 h in traditional open sun drying method. The drying period was considered 8 h as per initial moisture content and availability of solar radiation.

$$m_w = \frac{M_w}{t_d}$$

Where,

M_w - Mass of water evaporated during drying, kg
t_d - Assumed drying time, hours

$$\therefore m_w = \frac{5.04}{8}$$

= 0.63 kg h^{-1}

5. Total heat requirement, Q

$$Q = W_{bd} \times C_p \times (T_f - T_a) + M_{tw} C_w (T_f - T_a) + (M_w \times \lambda)$$

Where,

Q - Total heat required, kJ
W_{bd} - Bone dry weight of material, kg
C_p - Specific heat of Safed Musli, kJ kg^{-1} K^{-1}
T_f - Average temperature developed in dryer, °C
T_a - Average ambient temperature, °C

M_{tw} - Total quantity of water in product, kg
C_w - Specific heat of water, kJ kg^{-1} K^{-1}
M_w - Quantity of water evaporated from the product, kg
λ - Latent heat of vaporization of water, kJ kg^{-1}

$$\therefore Q = 0.84 \times 4 \times (50 - 30) + 5.16 \times 4.186 (50 + 30) + (5.04 \times 2250)$$

= 67.2 + 431.9952 + 11340
= 11839.1952 kJ

i. Energy required per hour, Q_t

$$Q_t = \frac{Q}{t_d}$$

Where,
Q_t - Energy required per hour, kJ h^{-1}
Q - Total energy required, kJ
t_d - Assumed drying time, h

$$\therefore Q_t = \frac{11839.1952}{8}$$

= 1479.89 kJ h^{-1}

6. Collector area required, A_c

$$A_c = \frac{Q_t}{I_t \times \eta}$$

Where,
A_c - Area of collector, m²
Q_t - Energy required, kJ hr^{-1}
I_t - Solar insolation, W m^{-2}
η - Thermal efficiency, %

$$\therefore A_c = \frac{1479.89}{600 \times 3.6 \times 0.35}$$

= 1.95 m^2

7. Volumetric air flow rate

The amount of air required to be expelled the desired moisture content from the drying chamber was estimated using the properties of ambient air, drying air and exhaust air as,

$$V_a = \frac{m_w}{\rho_a (H_f - H_i)}$$

Where,
V_a - Volumetric air flow rate, m^3 h^{-1}
m_w - Quantity of water to be evaporated, kg
H_f - Humidity ratio of exhaust air, kg of water per kg of dry air
H_i - Humidity ratio of ambient air, kg of water per kg of dry air

$$\therefore V_a = \frac{0.63}{1.14 (0.0343 - 0.025)}$$

= 59.42 m^3 h^{-1}

8. Design of chimney

Chimney was designed on the basis of the flow of air in the dryer which takes place due to draught caused by the density difference between the ambient air and hot air inside the dryer and considering the height of the chimney 0.40 meter.

i. Quantity of air needed to absorb M_w kg of water, Q_a

$$Q_a = \left[\frac{(M_w - \lambda)}{C_a \times \rho_a \times (T_h - T_e)} \right]$$

Where,
Q_a - Quantity of air needed to absorb M_w kg of water, m^3
M_w - Quantity of water evaporated from product, kg
λ - Latent heat of vaporization of water, kJ kg^{-1}
C_a - Specific heat of ambient air, kJ kg^{-1} k^{-1}
ρ_a - Density of ambient air, kg m^{-3}
T_h - Highest temperature of air in the dryer, °C
T_e - Temperature of exit air, °C

$$\therefore Q_a = \left[\frac{(2250 \times 5.04)}{1.005 \times 1.14 \times (65 - 38)}\right]$$
$$= 366.58 \text{ m}^3$$

ii. Quantity of air needed to remove moisture in 8 hours, M_a

$$M_a = \frac{Q_a}{t_d}$$

Where,

M_a - Quantity of air needed to remove moisture from the product, $\text{m}^3 \text{s}^{-1}$

Q_a - Quantity of air needed to absorb M_w kg of water, m^3

T_d - Assumed drying hours, h

$$\therefore M_a = \frac{366.58}{8}$$
$$= 45.82 \text{ m}^3 \text{ s}^{-1}$$
$$= 0.0127 \text{ m}^3 \text{ h}^{-1}$$

a) Draft produce, P_1

$$P_1 = H \times g \left(\rho_a - \rho_e\right)$$

Where,

P_1 - Draft produced, $\text{kg m}^{-1} \text{s}^{-2}$

H - Height of the chimney, m (H = 0.40 m. two in no.)

g - Acceleration due to gravity, m s^{-2}

ρ_a - Density of inlet air, kg m^{-3}

ρ_e - Density of exist air, kg m^{-3}

$$\therefore P_1 = 0.80 \times 9.81 \, (1.14 - 1.03)$$

$$= 0.8632 \text{ kg m}^{-1} \text{s}^{-2}$$

b) Density of inlet air, ρ_a

$$\rho_a = \rho_o \times \frac{T_o}{T_a}$$

Where,

ρ_a - Density of inlet air, kg m^{-3}

ρ_o - Density of air, (0.7734 kg m^{-3}), kg m^{-3}

$T_o = 273$ °k

T_a - Temperature of ambient air, °k

c) Density of exist air, ρ_e

$$\rho_e = \rho_o \times \frac{T_o}{T_a}$$

Where,

ρ_e - Density of hot exit air, kg m^{-3}

ρ_o - Density of air, (0.7734 kg m^{-3})

$T_o = 273$ °k

T_a - Temperature of ambient air, °k

d) Actual draft produced, P_2

$$P_2 = 80\% \ P_1$$

Where,

P_2 - Actual draft produced, kg m^{-2}

P_1 - Draft produced, kg m^{-1} s^{-2}

$$P_2 = 80\% \ 0.8632$$

$$= 0.6905 \text{ kg m}^{-1} \text{ s}^{-2}$$

iv. Velocity of exist air through chimney, V

$$V = \sqrt{2 \times \frac{P_2}{\rho_e}}$$

Where,

V - Velocity of exit air through chimney, m s^{-1}

P_2 - Actual draft produced, kg m^{-1} s^{-2}

ρ_e - Density of exist air, kg m^{-3}

$$V = \sqrt{2 \times \frac{0.6905}{1.03}}$$

$$= 1.15 \text{m s}^{-1}$$

a) Air flow rate through single chimney, Q

$$Q = \frac{M_a}{2}$$

Where,

Q - Air flow rate through single chimney, $m^3 s^{-1}$

M_a - Quantity of air required, $kg\ h^{-1}$

$$\therefore Q = \frac{0.0127}{2}$$

$= 0.0063\ m^3\ s^{-1}$

b) Cross section area of each chimney, A_{ch}

$$A_{ch} = \frac{Q}{V \times K}$$

Where,

A_{ch} - Cross section area of each chimney, m^2
Q - Flow rate through single chimney, $m^3 s^{-1}$
V - Velocity of exist air through chimney, $m s^{-1}$
K - Constant

$$\therefore A_{ch} = \frac{0.0063}{1.15 \times 0.4}$$

$= 0.01369\ m^2$

c) Diameter of chimney, D_c

$$D_c = \sqrt{\frac{A_{ch} \times 4}{\pi}}$$

Where,

D_c - Diameter of chimney, m
A_{ch} - Cross section area of each chimney, m^2

$$\therefore D_c = \sqrt{\frac{0.001369 \times 4}{3.14}}$$

$= 0.132\ m$

The other components of the drying system like flat collector, chimney, grate, stand and inlet vent were fabricated according to the design dimensions.

Performance evaluation of domestic solar dryer with reflector

The performance of the domestic solar dryer assisted with reflector at no load and full load test.

No load testing of domestic solar dryer with reflector

No load test of domestic solar dryer with reflector was conducted without loading the Safed Musli samples in dryer. The test was conducted between 8:30 to 17:30 h. The variation in temperature, humidity and air velocity inside the domestic solar dryer with corresponding to ambient parameters were recorded at 30 min intervals to evaluate the performance of the system.

Full load testing of domestic solar dryer with reflector

In full load test the Safed Musli samples were spread over the perforated sheet. The initial weight of the samples was recorded. Each sample of 100 gm was weighted regularly at an interval of one hour and simultaneously the temperature, relative humidity, solar radiation and wind velocity inside the domestic solar dryer was measured. Drying was conducted between 8:30 to 17:30 h day for with reflector. The drying trays were loaded with 6 kg Safed Musli for its drying. Inside and outside air temperature, relative humidity and wind speed were recorded at one hour interval during the test run.

Drying characteristics of Safed Musli

The drying depends on simultaneous heat and mass transfer phenomena and factors

dominating each process determine the drying behavior of the product (Agrawal *et al*., 2013).

Determination of moisture content

Initial moisture content of sample was determined by the hot air oven drying method. Samples were taken and weighed using electronic weighing balance of least count 0.01g. The samples were placed in hot air oven at 80± 5°C for 8 h. The drying rates were computed from the experimental data and drying characteristics curves i.e. moisture content (db) vs drying time, drying rate and moisture ratio vs drying time.

Determination of drying rate

The drying rate, (m_w) was determined from the mass of moisture to be removed by solar heat and drying time.

Drying efficiency of dryer (η)

The drying efficiency of solar dryer is the ratio of heat gained to the heat input. The heat input was calculated by considering total solar radiation incident in aperture area of solar drier during total drying hours in day.

Economic analysis of the solar drying system

The economic viability of any system was calculated through economic analysis of the system. For the success and commercialization of new technology, it is essential to know whether the technology is economically viable or not. Therefore, an attempt was made to evaluate economics of designed solar drying system. Different economic indicators such as NPW, BCR and PP etc. were used in computing the economics of the system. The economic

analysis was carried out by considering the following assumptions (Seveda *et al*., 2004).

1. The capacity of the domestic solar dryer system was 6 kg per batch.

2. The total finished product was produced per batch at 7 % wb.

3. No. of batches performed in the domestic solar dryer system.

4. The average purchase price of freshly harvested Safed Musli was Rs. 250 per kg.

5. The average selling price of the Safed Musli powder was Rs 1200 per kg.

6. The cost of domestic solar dryer was Rs. 10,330 /-.

7. The useful life of domestic solar dryer system was 10 years.

8. The cost of labour was Rs.180 per day.

9. The annual repair and maintenance cost of the system was 10% of the system for every 3 years.

The fabrication cost of domestic solar dryer assisted with reflector is given in table 2.

Sensory Evaluation

Sensory evaluation was carried out to estimate qualities of Safed Musli produced by each drying method. For determining quality of Safed Musli, colour, taste and texture were the main attributes for estimating the quality and consumer acceptance of Safed Musli powder produced (Winkeler *et al*., 1974). The overall quality of each dried sample was assessed by ten taste judge and asked to make categorical rating of the sample.

For sensory evaluation, the Safed Musli powder was placed in a coded paper and presented to all the ten judges. The parameters of the sensory evaluation were colour and appearance, texture, taste, overall acceptability. The judge was asked to evaluate the product on a hedonic scale (Guadogni *et al*., 1978) with the following rating table 3.

Statistical Analysis

In order to conduct the experiment in symmetric and efficient manner and keeping in view the levels of independent and dependent variables, the experiment were planned on completely randomized design (CRD). The effect of drying air temperature and quality of the dried product were analyzed statistically through two way analysis of variance (ANNOVA).

Results and Discussion

The domestic solar dryer assisted with reflector was designed for drying of 6 kg Safed Musli in a batch. The design specifications of domestic solar dryer assisted with reflector for drying of Safed Musli are computed as below (Amer *et al*., 2009).

No load testing of domestic solar dryer with reflector

The temperature developed in the domestic solar dryer integrated with reflector at no load condition during day time was recorded. The temperature in the domestic solar dryer during the month of December was observed in the range of 27.26 to 57.46, 26.93 to 56.46 and 27.1 to 57.66 °C at top, middle and bottom tray of drying chamber, respectively. Whereas, the average temperature in domestic solar dryer was observed to be 43.44, 42.78 and 42.80°C in top, middle and bottom trays respectively. The corresponding ambient temperature relative humidity and solar intensity was observed to be in the range of

19 to 26.5°C, 12 to 29 % and 89.8 to 666.7 W/m^2, respectively. The average ambient temperature, relative humidity and solar intensity were observed to be 22.70°C, 18.05 % and 425.45 W/m² respectively. The maximum temperature achieved in domestic dryer was 58.46°C at 13.30 h at corresponding ambient temperature (26.5°C), solar radiation (620 W/m^2) and RH (15 %).

Full load testing of domestic solar dryer with reflector

The domestic solar dryer with reflector was tested for drying of Safed Musli. The maximum temperature attained in domestic solar dryer was 58.46, 57.33 and 56.46°C at top, middle and bottom trays, respectively whereas the maximum ambient temperature and solar intensity was recorded as 37°C and 904.5 W/m^2, respectively. The average temperature in domestic solar dryer were recorded as 47.45, 46.83 and 46.89°C at top, middle and bottom trays, respectively. The average ambient temperature, solar intensity, relative humidity and wind velocity was obsereved to be 33.48°C, 718.3 W/m^2, 22.55 % and 0.98 m/s, respectively. It was observed that drying of Safed Musli in domestic solar dryer took 8 h. Figure 2 revealed that the reflector radiated solar radiation in the drying chamber during clear sunshine hours and therefore achieved more temperature in drying chamber of domestic dryer. The drying of Safed Musli was achieved in one day only (9:00 to 17:00 h). The average drying time requirment for drying of Safed Musli in domestic solar dryer with reflector was found less than other drying systems(Bolaji *et al*., 2011).

Safed Musli were dried in domestic solar dryer and its drying characteristics were studied. The average moisture content of Safed Musli samples placed in T1, T2 and T3 trays reduced from 651.5 to 4.5, 654.7 to 7.7

and 656 to 14.5 % (db) in 8 h, respectively in domestic solar dyer integrated with reflector.

Whereas the average moisture content of Safed Musli sample reduced from 613 to 7.8 % (db) in 12 h for open sun drying in the month of March, 2015. Figure 3 revealed that the drying rate of Safed Musli dried in T1, T2 and T3 trays of domestic solar dryer integrated with reflector varied from 1.3384

to 0.0047, 1.2308 to 0.0224 and 1.2214 to 0.0254 gm/100gm bdm min, respectively

Figure 3 revealed that the drying rate of Safed Musli dried in T1, T2 and T3 trays of domestic solar dryer integrated with reflector varied from 1.3384 to 0.0047, 1.2308 to 0.0224 and 1.2214 to 0.0254 gm/100gm bdm min, respectively and average drying rate was found to be 0.5526, 0.54103 and 0.53455 gm/100gm bdm min, respectively.

Table.1 Initial design conditions and assumptions made for design of domestic solar dryer

S. No.	Design parameters	Values
1	Type of drying product	Medicinal Plant
2	Initial moisture content (M_i), %	86 (wb)
3	Final moisture content (M_f), %	12 (wb)
4	Weight of material (W_g), kg	6
5	Location	Dr. PDKV, Akola
6	Ambient air temperature (T_a), ºC	30
7	Ambient air relative humidity (Rh_a), %	50
8	Specific heat of water (C_w), kJ kg^{-1} C^{-1}	4.186
9	Specific heat of ambient air (C_a), kJ kg^{-1} C^{-1}	1.005
10	Specific heat of Safed Musli (C_p), kJ kg^{-1} C^{-1}	4.0
11	Average sunshine hours, h	08
12	Drying air temperature (T_h), ºC	65
13	Exhaust air temperature (T_e), ºC	38
14	Latent heat of vaporization of water (λ), kJkg^{-1}	2250
15	Efficiency of dryer (η), %	35
16	Density of exit air (ρ_e), kg m^{-3}	1.09
17	Density of ambient air (ρ_a), kg m^{-3}	1.14
18	Height of chimney (H), m	0.40
19	Gravity constant (I_{sc}), m s^{-2}	9.81
20	Global radiation at Akola, W m^{-2}	600

Table.2 Cost of fabrication of domestic solar dryer assisted with reflector

S. N.	Material and specifications	Quantity	Rate (Rs)	Total (Rs.)
1	C.R sheet for drying chamber (24 gauge)	22 kg	70/kg	1540
2	M.S. angle 25 ×25× 5mm thickness	13 kg	60/kg	900
3	Galvanize sheet for chimney (24 gauge)	2	150	300
4	G.I mesh for drying tray	40 sq.ft.	20/sq.ft	800
5	Reflector SS sheet in M.S angle frame	1	1000	1000
6	U.V Film	3 sq. m	90/ sq.m	270
7	Shade net	3 sq. m	45/ sq.m	135
9	Thermocol Insulation, 10mm	15 sq.ft.	3/ sq.ft.	45
10	Colouring	1.5 lit.	360/lit.	360
11	Flat plate for trays 25mm×5mm	12kg	600/kg	720
12	Lobour	-	-	500
13	Miscellaneous	-	-	4000
			Total	10,330

Table.3 Sensory evaluation rating scale

Rating	Scale
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like or dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Table.4 Design parameters of domestic type solar dryer

Sr. no.	Design Parameters	Specification
1	Initial moisture content in Safed Musli, (% wb)	86
2	Final moisture content in Safed Musli, (% wb)	12
3	Total quantity of water in product, M_{tw}, kg	5.16
4	Bone dry weight of material, W_{bd}, kg	0.84
5	Quantity of water to be removed, M_w, kg	5.04
6	Drying rate, m_w, kg h^{-1}	0.63
7	Total energy required, Q, kJ	11839.1952
8	Energy required per hour, Q_t, kJ h^{-1}	1479.89
9	Collector area required, A_c, m^2	1.95
10	required volumetric air flow rate, V_a, m^3 h^{-1}	59.42
	Design of chimney	
11	Quantity of air needed to absorb M_w kg of water, Q_a, m^3	366.58
12	Quantity of air needed to remove moisture in 8 hours, M_a, m^3 h^{-1}	0.0127
13	Draft produce, P_1, kg m^{-1} s^{-2}	0.8632
14	Density of inlet air, ρ_a, kg m^{-3}	1.14
15	Density of hot exist air, ρ_e, kg m^{-3}	1.044
16	Actual draft produced, P_2, kg m^{-1} s^{-2}	0.6905
17	Velocity of exist air through chimney, V, m s^{-1}	1.15
18	Air flow rate through single chimney, Q, m^3 s^{-1}	0.0063
19	Cross section area of each chimney, m^2	0.01369
20	Diameter of each chimney, m	0.15

Table.5 Mean score of sensory characteristics of Safed Musli of different samples

Sample Attributes	Colour	Texture	Flavor	Overall acceptability	S.E. (M)	C.D. At 5%	C.V. (%)
With reflector	9	8.6	8.7	8.5	1.03	3.29	29.13
Without reflector	8	7.9	7.3	7.8	1.01	3.22	29.92
With shade net	7.2	6.6	7.1	7.5	0.9	2.93	26.9
Open sun drying	4.2	4	4.3	5.2	0.7	2.27	19.71

Table.6 Economic analysis of domestic solar dryer with reflector

S.N.	Description	Dryer Assisted With Reflector
1.	Initial investment (Rs)	10195.00
2.	Annual use no. of batches	180
3.	Cost of raw material (Rs yr^{-1})	2,70000
4.	Cost of labour for drying (Rs yr^{-1})	32,400
5.	Operation and maintenance cost (Rs)	30,2400
6.	Cost of pretreatment (Rs yr^{-1})	400
6.	Total dried product (kg)	270
7.	Total cost of finishade product at Rs 300/kg	486000
8	B:C ratio	1.68
9	Payback period, month	1
10	NPW (Rs.)	78084.73

Fig.1 Domestic solar dryer assisted with reflector

1	Chimney hood
2	Chimney
3	Door
4	Main frame
5	Trays
6	Transparent cover
7	Reflector
8	Tracking adjustment
9	Drying chamber
10	Air vent
11	Insulation
12	Castor wheel

Front isometric view
Scale: 1:1
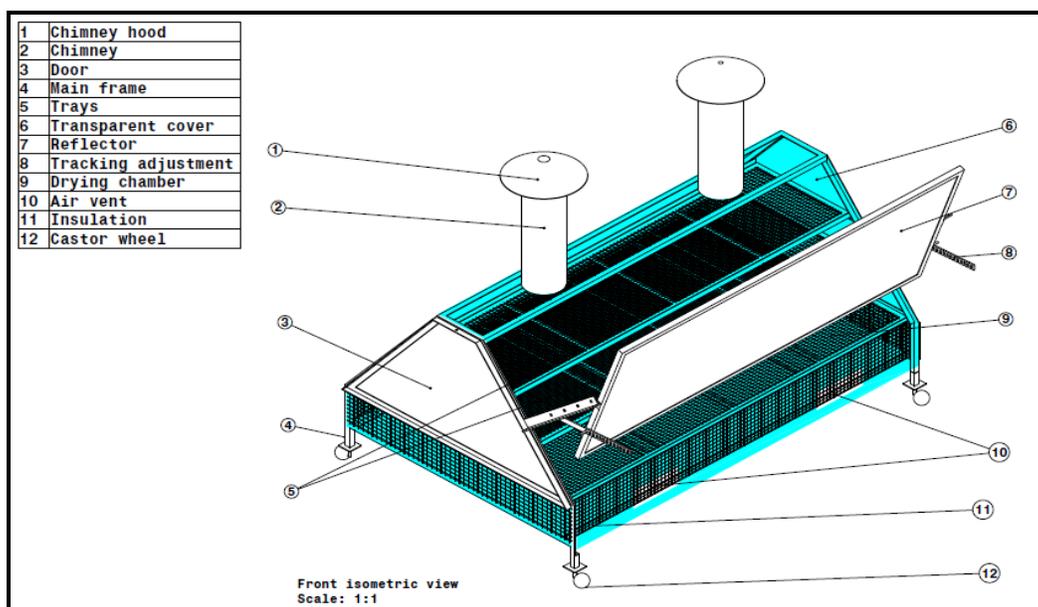
Fig.2 Temperature variation in the domestic solar dryer integrated with reflector at full load condition
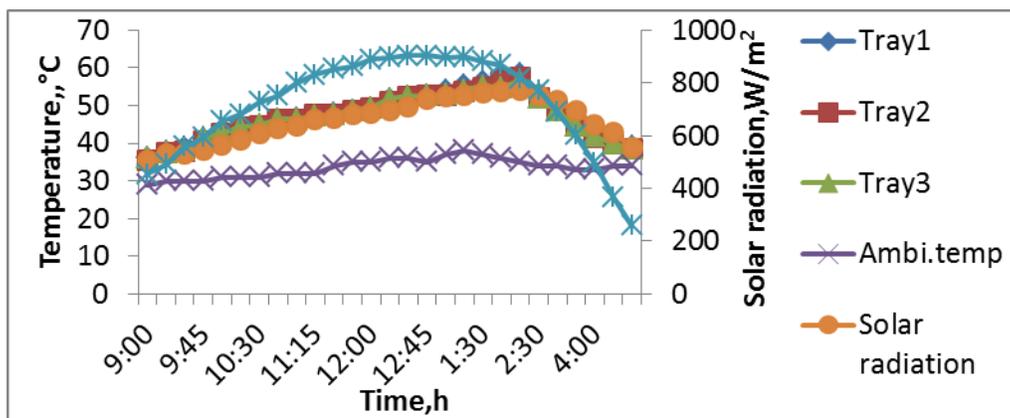

Fig.3 Variation of drying rate and moisture ratio of Safed Musli in domestic solar dryer with reflector
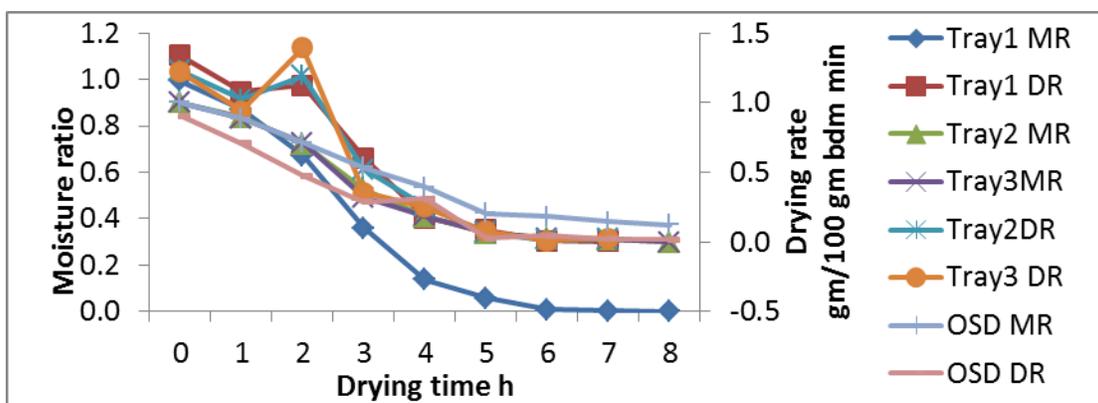

Fig.4 Variation of drying efficiency of domestic solar dryer with and without reflector and with shade net
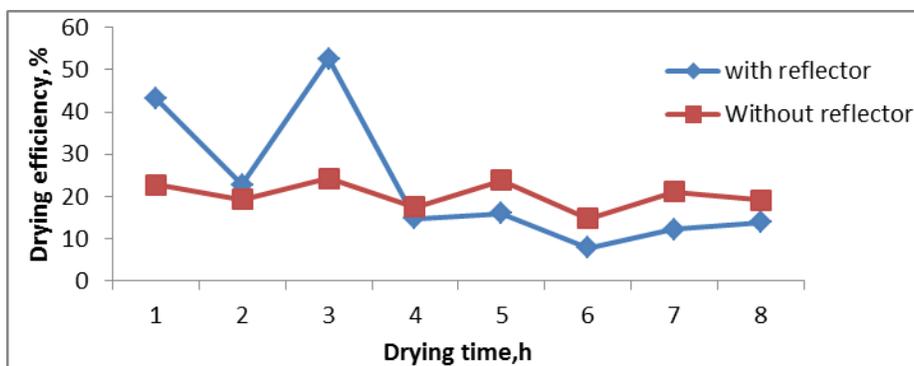
The drying rate of open sun dried Safed Musli (OSD) was found to be 0.9048 to 0.0183 gm/100gm bdm min. The average drying rate of open sun dried sample was found to be

0.34776 (Boonyasari *et al*., 2011; Deshmukh *et al*., 2014).

Drying efficiency of domestic solar dryer for drying of Safed Musli based on the experimental data was calculated by considering the total moisture evaporated during the drying process associated with total heat input and heat gained by the product. The average drying efficiency of Safed Musli samples dried in domestic solar dryer with, without reflector was found to be 22.92, 20.32 respectively (El-Sabaii and Shalaby, 2012) (Fig. 4).

The data presented in table 5 indicate that the values obtained during sensory evaluation were significant for organoleptic characteristics like colour and appearance, texture, flavor and overall acceptability. On the basis of standard error mean, critical difference and coefficient of variance, the Safed Musli dried in domestic solar dryer was acceptable and good quality and found to be suitable for consumption (Muller and Heindll, 2006).

Economics of domestic solar dryer for drying of Safed Musli

The economic feasibility of domestic solar dryer with reflector, without reflector and with shade net for drying of Safed Musli was calculated by considering initial investment, average repair and maintenance cost, cost of raw material. The average parameter was drawn on the basis of experimental results are given in table 6 (Kalbande *et al*., 2013).

In conclusion, the experiment was conducted in the month of March 2015. In the drying study of Safed Musli drying time, drying rate and moisture ratio were determined in domestic dryer without reflector, with reflector. Domestic solar dryer system was designed as per designed specification with a solar collector area of 1.95 m^2 with drying chamber of size 1.5m × 1.0m × 0.65m, for drying capacity of 6 kg Safed Musli in a batch. The average drying efficiency of Safed Musli samples dried in solar domestic dryer with and without reflector was found to be 22.92 and 20.32 and drying time for 6 kg of Safed Musli for reducing its moisture content from 86 to 7% (wb) was found to be 8 h, 8.5 h respectively. Economic indicator viz., payback period with benefit cost ratio and Net Present Worth of the system for drying of Safed Musli in domestic solar dryer with reflector was found to 1 month, 1.68 and Rs. 78084.73, respectively. Since NPV is positive the drying in domestic dryer was economically viable.On the basis of sensory evaluation the safed musli dried in domestic dryer give better quality in terms of colour, texture, appearance and taste than the open sun dried samples and acceptable for consumption.

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