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Recommendation proposal

Design and development of portable folding type solar dryer.

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PART –I GENERAL INFORMATION

1.	**Project Code**	
2	**Project Title**	Design and development of portable folding type solar dryer.
3	**Name of Department Where the project was undertaken** **a) Name of Department** **b) Location of Project**	 Department of Electrical and Other Energy Sources Faculty of Agricultural Engineering & Technology Dr.B.S.Konkan Krishi vidyapeeth, Dapoli Department of Electrical and Other Energy Sources Faculty of Agricultural Engineering& Technology Dr.B.S.Konkan Krishi vidyapeeth, Dapoli
4	**Name of Scientist**	Dr. Y.P. Khandetod , Professor and Head
5	**Name of Co-scientists**	Dr. A.G. Mohod, Associate Professor Er. H.Y. Shrirame, Sr. Research Assistant
6	**Objectives**	1. Design and fabrication of portable folding type solar dryer. 2. Performance evaluation of developed portable folding solar dryer for drying of agriculture produce.
7	**Year of start**	2012-13

PART-II TECHNICAL INFORMATION

8. Background of Project:

Solar dryer is beneficial to attain higher temperature than atmospheric temperature. It also prevents contamination of product to be dried. One of the important advantages of the technology is that it reduces the losses while drying due to birds etc. and avoids contamination from dust.

In Konkan sun drying practices are carried out in the house yard for mango leather, kokum, jackfruit leather, raw mango flex. These practices are seasonal, so people need portable type solar dryer to dry agriculture produce as per the seasonal availability. The Commercially available fixed- type solar dryers if constructed in house yard it will remain idle in offseason and occupy the space permanently.

The solar energy in Kokan region is available for 8 to 9 months in a year with effective average sunshine hours ranging from 6.5 to 8 hours per day. The average solar energy ranges between 450-600 W/m2 day.

So in the present study attempt is being made to design and develop a portable and foldable type solar dryer which may solve the problem of storing the dryer in off season to some extent. The dryer being portable is convenient for handling and transporting. On the other hand it can be kept safely away degradation due to environmental factors when not in use. It can be stored easily as it requires minimum space due to its folding ability. During off season the various parts such as tray and box being detachable can be used for other purpose. The manufacturing of such dryer will also generate rural employment. Hence keeping this in a view the project is undertaken for drying local agriculture produce. Aonla pieces, potato chips, vegetables were are tested to see the feasibility of the dryer.

9. Technical Details of Project:

Design Consideration for D-type portable Folding Type of Solar Dryer

The following points were considered in the design of the natural convection solar drying system.

A) Amount of moisture to be removed, W_w (kg)

Amount of moisture to be removed from a given quantity of wet Aonla pieces to bring the moisture content to a safe storage level in a specified time was determined by using relationship (1).

$$Ww = Wg \times \frac{(M_i - M_f)}{(100 - M_f)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,

Wg = Initial mass of the wet Aonla pieces, kg

Mi = Initial moisture content of the Aonla pieces, % wet basis

Mf = Final moisture content of the Aonla pieces, % wet basis

B) Average drying rate, W_{dr} (kg/hr)

The drying time, during which the drying takes place, i.e. the effective sunshine hours may be considered as 9:00 AM to 5:00 PM. It was considered that 20 hours (appox three days) would be required to reduce the moisture content up to safe storage level. Average drying rate was determined from the mass of moisture to be removed by solar heat and drying time by the relationship (2).

$$W_{dr} = \frac{W_w}{t_d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where,

t_d - total drying time required for removing the *Ww* kg of the water from the wet Aonla pieces, hours

C) Quantity of air required for drying, W_a (kg)

The quantity of air needed for drying was estimated from the energy balance equations or from the psychometric chart. Both methods were used to determine the amount of air needed to dry the particular quantity of wet Aonla pieces. The basic energy balance equation for the drying process

$$W_a = \frac{(W_w \times L)}{C_a \rho_a (T_i - T_f)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,

Wa = Quantity of air required for drying, kg

Ww = Quantity of water evaporated, kg

L = Specific latent heat of vaporization of water from wet Aonla pieces, (kJ/kg)

$C\,a$ = specific heat capacity of the air at constant pressure, (kJ/kg °C)

ρ_a = density of drying air, kg/m^3

Ti= Initial temperature of the drying air, °C

Tf = Final temperature of the drying air, °C

D) Volume flow rate of air required, Q_a (m^3/hr)

Volume flow rate of air required was determined by considering weight of air and total drying time was given as follows

$$Q_a = \frac{W_a}{t_d \ \rho_a} \quad \text{.................................} \ (4)$$

E) Useful heat energy required, E_u (kJ)

Total useful energy required to evaporate moisture was determined by using expression (5).

$$E_u = Q_a C_a \rho_a \left(T_i - T_f\right) t_d \quad \text{..............................} \ (5)$$

Where,

Q_a = Volume flow rate of air required, m^3/hr

E_u = Total useful heat energy required evaporating the moisture, kJ

F) Total collector area, A_c (m^2)

From the total useful heat energy required to evaporate the moisture from the Aonla pieces and the net radiation received by the collector, the solar drying system collector area A_c in m^2 was calculated from the expression (6).

$$A_c = \frac{E_u}{I\eta} \quad \text{..} \ (6)$$

Where,

E_u = total useful heat energy required evaporating the moisture, kJ

I = total global radiation on the horizontal surface during the drying period, kJ/m^2.

η = collector efficiency, 30% to 50% (Basunia and Abe 2001).

G) Dryer dimensions

The dimensions of the dryer were calculated by the expression 7.

$Area = D \times L$ ……………………………………….. (7)

Where,

Area= collector area Ac, m^2

D= diameter of dryer (width of dryer), m

L= length of the dryer, m

H) Number of tray

Numbers of trays were calculated by the relationship between actual drying area from the density of Aonla pieces and total collector area.

Number of trays = Actual drying area/ total collector area

I) Air vent dimensions

The air vent area was determined by considering volumetric airflow rate and wind speed as in expression (8).

$$A_v = \frac{Q_a}{V_w} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where,

A_v= area of the air vent, m^2.

V_w= wind speed, m/h

J) Dimensions of chimney

Since airflow rate in the dryer took place due to the draft caused by the pressure difference between outside cold air and inside hot air.

$P=0.000308\ g\ (T_i-T_f)\ H$ …… (9)

Where,

P= pressure difference between outside cold air and inside hot air, Pa.

g= acceleration due to gravity 9.81 m/s^2.

H= height of the chimney, m.

Actual draft was assumed to be 75% of this draft (*P*).

Actual draft (*P1*) =0.75 x *P*.

Velocity of exit air (c) = $\sqrt{\left(\frac{2 \times P1}{\rho e}\right)}$ …….. (10)

Volume of exit air (*ve*) = quantity of air in kg / ρe.

Rate of exit air (*qe*) = *ve* / drying time

Cross sectional area of chimney (*ac*) = *qe* / *c*

Hence diameter of chimney (*d*) = (4 x *ac* /Π) $^{0.5}$

Where, c is velocity of existing air

Upper diameter (*d1*) of chimney was 75% of the lower one (*d*).

So with the above equation diameters *d* and *d1* and height *H* of chimney was determined.

Design and Development of D-type portable Folding type Solar Dryer for Aonla Candy drying

In direct type solar dryer the heated air in the drying chamber was passed through the bed of the wet Aonla pieces and at the same time the top surface of these pieces absorbs the solar energy received directly through a transparent cover. The essential components of the dryer are air inlet (air vent), drying chamber, dome and chimney for discharging air at upper elevation. Collector area was painted with black colour to increase absorbtivity of solar radiation. UV stabilized 200 micron gauge polythene sheet was used as glazing for the D-type portable and folding type solar dryer. The chimney was also provided at the top to remove the moist air and also to create the draft. When the ambient air enters the drying or heating chamber from the ports provided in sidewall and air gets heated. The heated air expands and becomes relatively light in weight. The light air was then impelled upwards by buoyancy force. The product gets dried simultaneously by both convection and conduction principle.

While designing the D-type(portable folding type) solar dryer some design considerations and assumptions were made. The design assumptions are depicted in Table 1. Design parameters were depicted in Table 2.

The schematic view of developed D-type portable folding type of solar dryer for aonla candy drying is shown in plate 1. The pictorial view of the D-type portable folding type of solar dryer is shown in Plate 2-Plate 4.

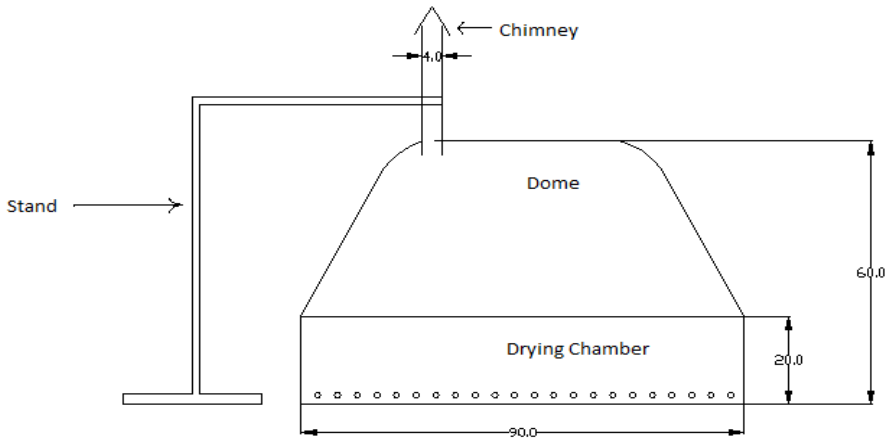
Table 1- Drying assumptions for design of D-type portable folding type of solar dryer for Aonla Candy drying

Sr. No.	Items	Condition or Assumption
1.	Location	Dapoli
2.	Mode of Drying	Natural convection
3.	Material to be Dried	aonla Candy (Sugar treated wet aonla pieces)
4.	Drying period	October to November
5.	Quantity of material to be dried per batch	2 Kg

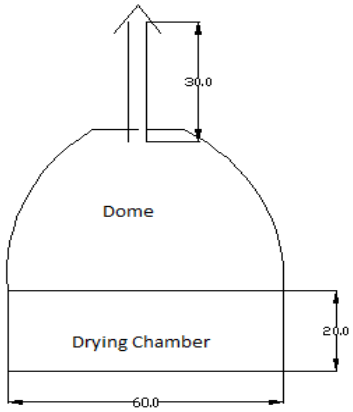
	(W_g)	
6.	Initial moisture content (M_i)	74%(wb)
7.	Final moisture content for storage (M_f)	20%(wb)
8.	Drying time (t_d)	12 hrs
9.	Ambient air temperature	28.5 °C
10.	Ambient humidity	70 %
11.	Wind speed (V_e)	2 m/sec
12.	Initial Temperature of drying air	58 °C
13.	Final Temperature of drying air	41 °C
14.	Collector efficiency (η)	35%
15.	Specific Latent Heat of Vaporization of Water (L)	2260 kJ/kg
16.	Specific Heat of Air (C_a)	1.005 kJ/kg ^oC
17.	Density of Air at Ambient Temperature (ρ_a)	1.115 kg/ m^3
18.	Density of Exit Air (ρ_e)	1.0539 kg/ m^3

Table 2-Specifications of D-type portable folding type solar dryer for drying of aonla Candy

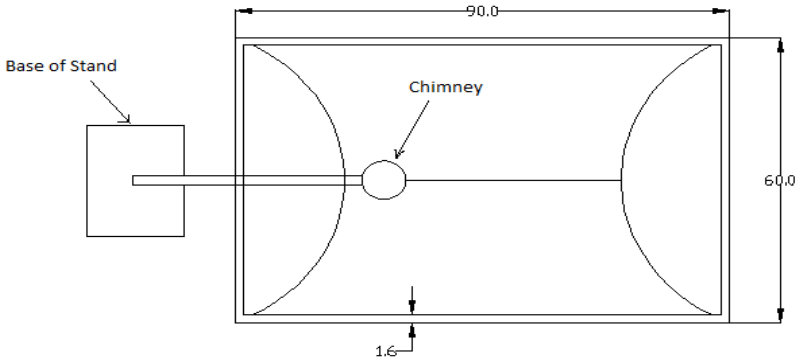
Sr. No.	**Parameters**	**Value**
1.	Mass of water to be evaporated, W_w	1.32 kg
2.	Average drying rate, W_{dr}	0.3771 kg/hr
3.	Length of dryer, L	0.9 m
4.	Width of dryer, W	0.6 m
5.	Numbers of tray	1
6.	Area of the Air Vent (A_v)	0.001256 m^2
7.	Pressure Difference Between Outside Cold Air and Inside Hot Air (P)	0.041 Pa
8.	Actual Draft ($P1$)	0.031 Pa
9.	Velocity of Exit Air (c)	0.2385 m/sec
10.	Volume of Exit Air (v_e)	148.59 m^3
11.	Rate of Exit Air (q_e)	14.15 m^3/hr
12.	Solar collector area, A_c	0.54 m^2
13.	Quantity of air required for drying, W_a	156.6 kg
14.	Volumetric air flow rate, Q_a	13.37 m^3/hr
15.	Total energy required in drying, E_u	2674.87 kJ
16.	Diameter of chimney, $d1$	0.04 m
17.	Height of chimney, H	0.3 m



a) Front View



b) Side View



c) Top View

Plate. 1 Schematic View of D-type portable and Folding Type Solar Dryer

Plate 2. Portable and Foldable type Solar Dryer in Construction

Plate 3. Box of Portable and Foldable type Solar Dryer

Plate 4. Pictorial view of the D-type portable folding type solar dryer

A material required for fabrication of prototype D-type portable and folding type of solar dryer for Aonla candy drying and the total cost of fabrication as per material rates (2013) are summarized in Table 3.

Table 3- Material and cost of fabrication for D-type portable and folding type of solar dryer for drying of aonla candy

Sr. No.	Material required	Quantity of material	Total cost (Rs.)
1.	Plywood (16 mm)	0.9 X 1.2 m	645
2.	Aluminium wire frame	0.6 m^2	340
3.	Fevicol	0.1 kg	38
4.	Tekus (nails)	0.1 kg	14
5.	Polythene sheet (200 gauge)	2m	110
6.	Black board paint	0.5 lit	90
7.	Screws	1 dozen	12
8.	Velcro	7 m	100
9.	Labour cost		600
			Total cost = ₹. 1949/-

Performance Evaluation of D-type portable Folding type Solar Dryer:

The performance evaluation was carried by conducting the no load test for testing designed parameters and load test with comparison between open sun drying and drying inside the dryer.

Sample Preparation

Samples were prepared from fresh aonla (*Emblica officinalis*), brought from market. The 5 kg aonla were washed and boiled in water for approximately 5 minutes. Then 2.5kg aonla pieces were pre-treated with sugar and 2.5kg aonla pieces kept as such, then they were cut and separated into slices of thickness 6 to 7 mm. The thickness was measured by using vernier calliper. After one day pieces of aonla began to float in sugar solution. The pieces were kept in this condition for one more day and then pieces were drawn out of solution.

Performance Evaluation of Portable and Foldable type Solar Dryer:

Then from the tray randomly ten samples were selected and weighed. The weight reduction of the sample was observed at 30 minutes interval by using weighing balance. Initial moisture content of Aonla sample was calculated using standard hot air oven method (A.O.A.C. 1990).

No Load Testing:

No load test of portable and foldable type solar dryer was carried out to evaluate the design parameters without loading of dryer. Different parameters like temperature at various points inside the dryer relative humidity, solar intensity and wind velocity was measured at an interval of half hour on a clear sunny day. The following parameters are measured,

Temperature at middle of the tray ($T_1{}^OC$)

Temperature at chimney ($T_{chimney}{}^OC$)

Ambient Temperature ($T_{amb}{}^OC$)

Humidity of the atmosphere (RH_{in}%)

Humidity inside the dryer (RH_{out} %)

Wind velocity (Vwind, m/sec)

Solar insolation (W/m^2)

Load Testing:

Load test of portable and foldable type solar dryer was carried out to evaluate the design parameters with loading of Aonla in dryer. Different parameters like temperature at various places, relative humidity, solar intensity and wind velocity were measured at an interval of half hour in a clear sunny day. The following parameters are measure,

Temperature at middle of the tray ($T_1{}^OC$)

Temperature at chimney ($T_{chimney}{}^OC$)

Ambient Temperature ($T_{amb}{}^OC$)

Humidity of the atmosphere (RH_{in}%)

Humidity inside the dryer (RH_{out} %)

Wind velocity (Vwind, m/sec)

Solar insolation (W/m^2)

Various instruments used for measuring parameters are given below:

Digital Thermometer

Hygro-Thermometer

Weighing balance

Anemometer

Solar energy meter

Performance Evaluation of D-type portable folding type solar dryer for drying of Aonla Candy in winter season.

The performance evaluation was carried out during the winter season for testing of design parameters of D-type portable and folding type solar dryer by conducting no load test and load test with Aonla candy in comparison with open sun drying. The results obtained are summarised as below.

No Load Test in winter season:

The dryer was tested without loading and different atmospheric parameters were measured like temperature, relative humidity and solar intensity at every half hour interval was recorded. The change in temperature, humidity and solar insolation with respect to time at various locations are depicted in (Fig.1) and (Fig.2).

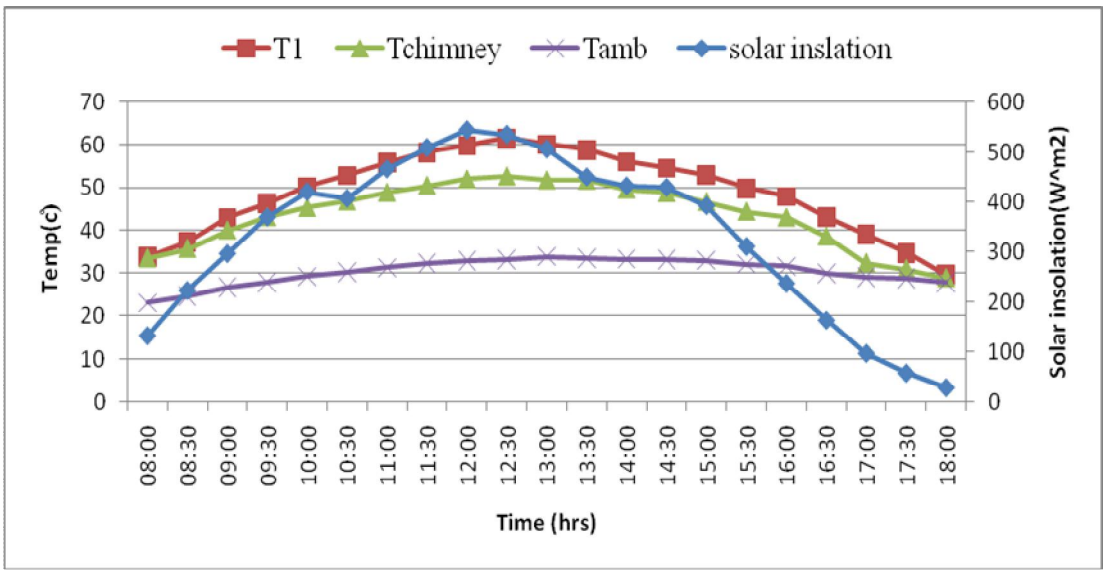


Fig. 1 No Load Test Temperature variation with Solar Insolation in winter season

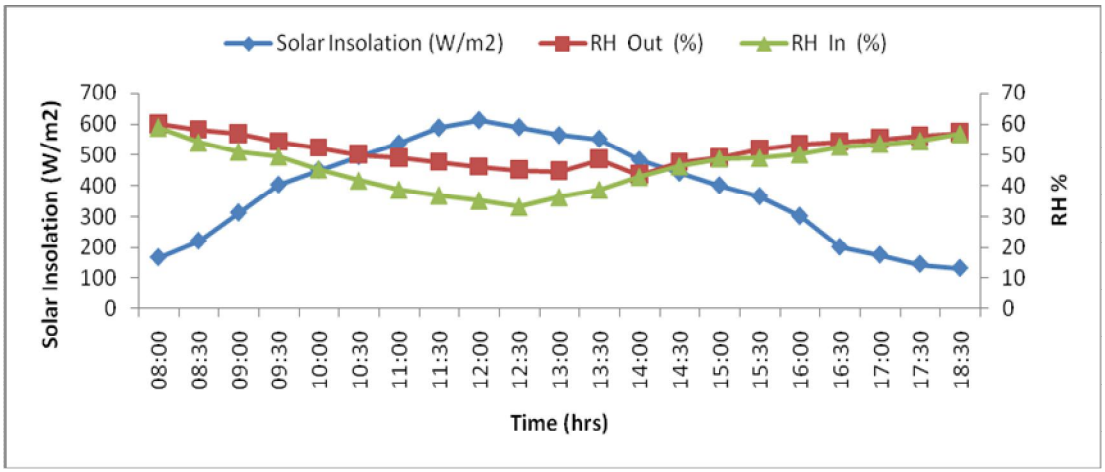


Fig. 2 No Load Test RH variation with Solar Insolation in winter season

The No Load test was carried out at Energy Park of CAET, Dapoli. The temperature inside the portable and foldable type solar dryer increased with solar insolation and attained peak value 63.33 ^{o}C at 12:30 hrs, the peak atmospheric temperature value attained was 34.5 ^{o}C at 12:30 hrs where as minimum ambient temperature 22 ^{o}C was observed at the start of the test at 8:00 am (Fig. 1). Solar insolation also varied according to time of the day reaching its peak value as 515 W/m^2 at 12:00 hrs (Fig. 1). The atmospheric humidity varied from 44.43 per cent to 57.20 per cent respectively where as relative humidity inside the portable and foldable type solar dryer varied from 36.30 per cent to 50.13 per cent at 13:00 and 18:00 hrs respectively (Fig.2).

Performance Evaluation of D-type portable folding type solar dryer for drying of vegetables in summer season.

The performance evaluation was carried out for testing of design parameters of D-type portable and folding type solar dryer by conducting no load test and load test in summer season with different vegetable like Spinach, Fenugreek, Cauliflower and Cabbage in comparison with open sun drying. The results obtained are summarised as below.

Sample Preparation:

Samples were prepared from fresh vegetable :-Spinach, Fenugreek, Cauliflower and Cabbage, purchased from local market. The vegetables were washed in water for approximately 5 minutes then they were cut small pieces. Then vegetables were pre-treated with boiled water with two per cent salt.

No Load Test in summer season:

The dryer was tested without loading in summer season with different atmospheric parameters were measured like temperature, relative humidity and solar intensity at every half hour interval was recorded. The change in temperature, humidity and solar insolation with respect to time at various locations are depicted in (Fig.3) and (Fig.4).

Under no load condition of solar drying, radiation and temperature inside the collector were measured with time of day in the interval of 30 minutes were plotted in (Fig.3). The No Load test was carried out at Energy Park. The temperature inside the D-type portable folding type solar dryer increased with solar insolation and time of the day and attained peak value 72.8 ^{o}C at 13:00 hrs, whereas peak ambient temperature value attained was 39.2 ^{o}C at 13:00 hrs where as minimum temperature was observed at the start of the test at 8:00 am (Fig.3).

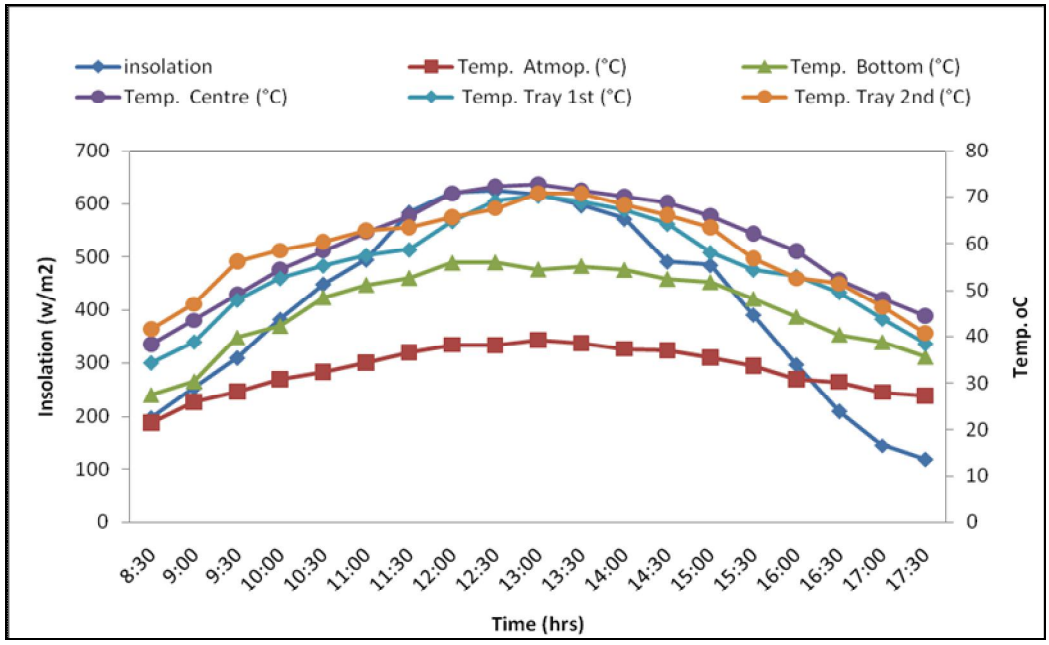


Fig. 3 No Load Test Temperature variation with Solar Insolation in summer season.

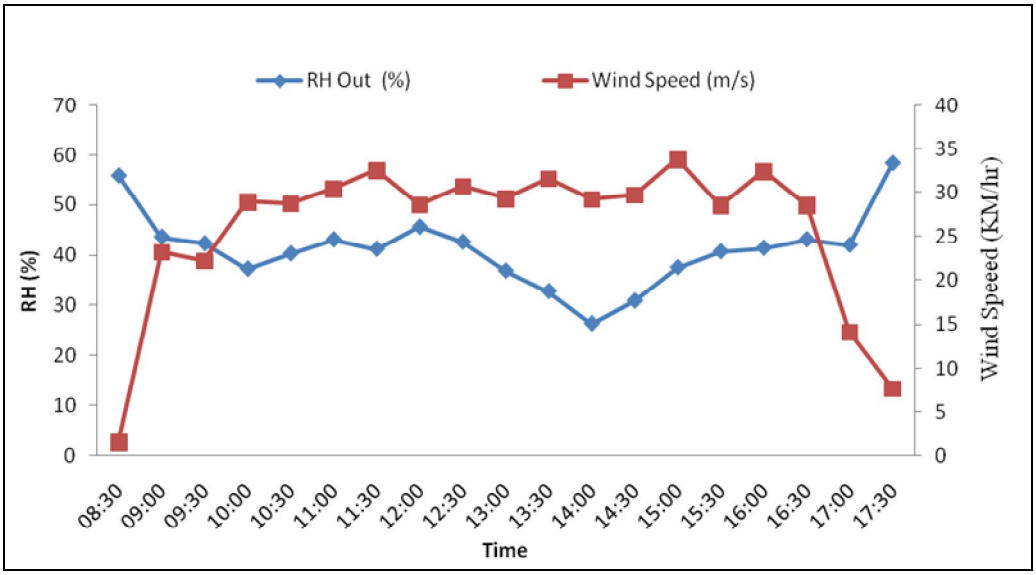


Fig.4 No Load Test RH variation with Solar Insolation in summer season

Solar insolation also varied according to time of the day reaching its peak value as 624 W/m^2 at 12:30 hrs (Fig.3). The atmospheric humidity varied from 42.7 per cent to 58.4 per cent at 12:30 and 18:00 hrs respectively (Fig.4).

In no load test temperature inside the dryer increases from bottom to top due to decreasing air density as it passes through hottest zone. Bottom of dryer contain minimum temperature because of opening for fresh air entrance are provided just below the tray in dryer, where the density of air is higher as compare to air density above the trays. As the temperature increased humidity decreased, as per this phenomenon, humidity's inside the dryer was lower as compared to outside condition of dryer. Solar energy collection efficiency was more inside D-type portable folding type solar dryer due to its exposed top to the sun and as it was perfectly airlocked so as to produce better hot air draft.

Moisture reduction study during load test for drying of Aonla Candy under portable and foldable D- type solar dryer in winter season.

There were two different types of wet aonla pieces used for drying under portable solar dryer, i.e. Two kg pieces which were sugar treated and another two kg were without sugar. Various drying parameters like solar insolation, atmospheric temperature and atmospheric relative humidity with respect to drying time were observed and compared with the parameters inside the portable and foldable type solar dryer.

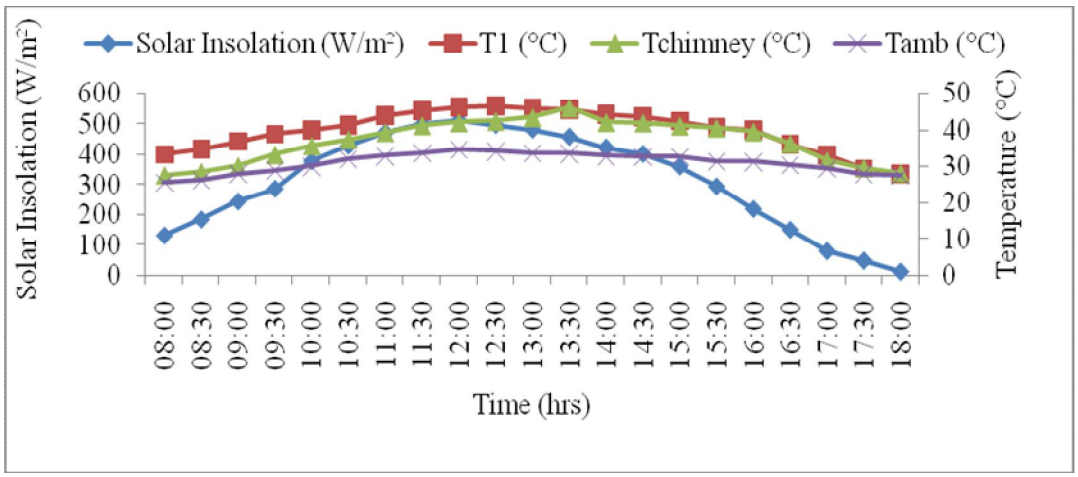


Fig.5 Load Test Temperature variation with Solar Insolation in winter season.

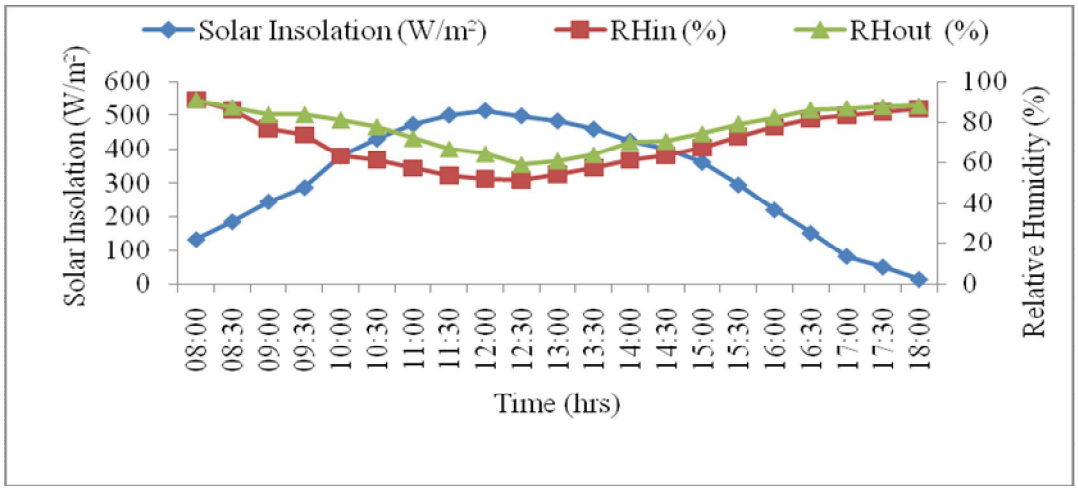


Fig. 6 Load test RH variation with Solar Insolation in winter season.

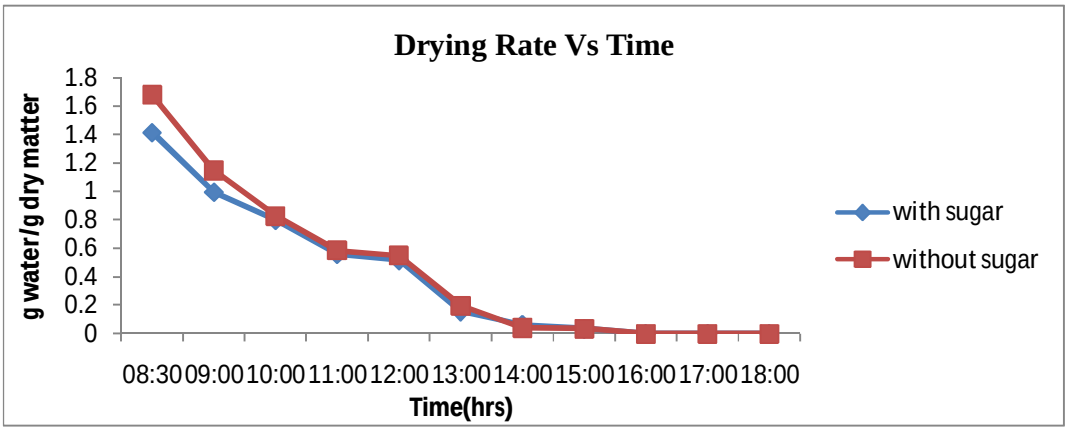


Fig. 7 Drying rate for load test in winter season.

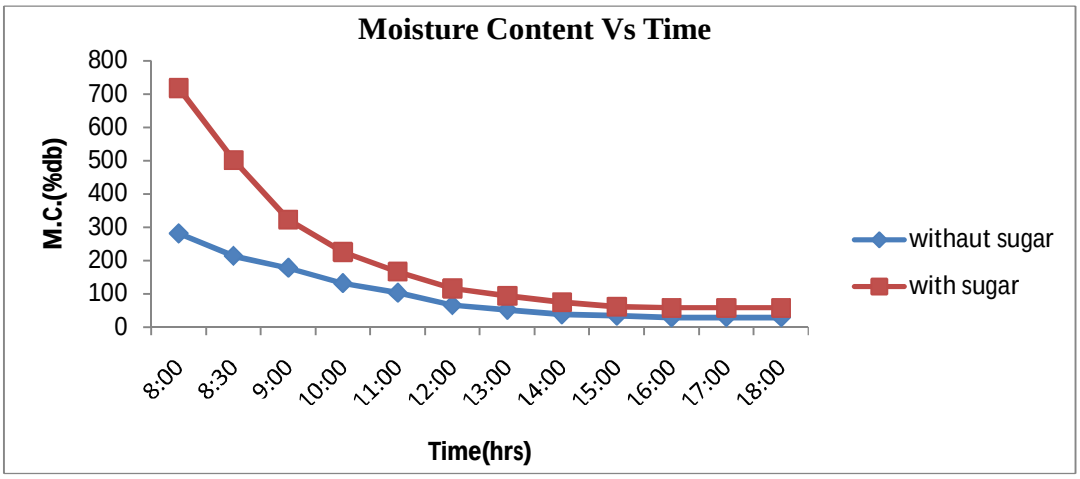


Fig. 8 Moisture Content Reduction for load test in winter season.

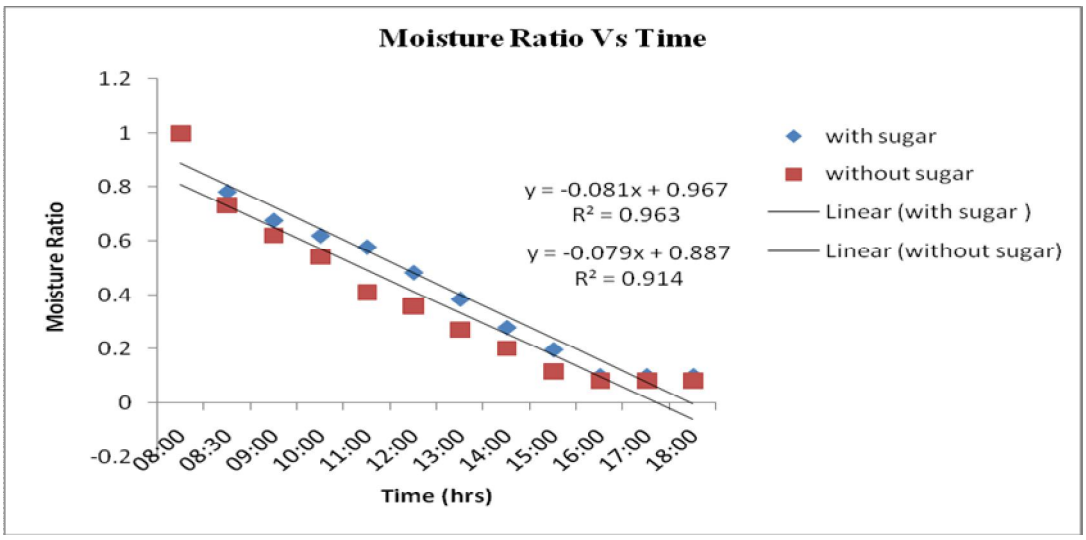


Fig. 9 Moisture ratio variation for load test in winter season.

As the temperature inside the portable and foldable type solar dryer increased the relative humidity decreased. Solar insolation increased from morning to afternoon and attained peak value 514 W/m^2 at 12:00 hrs and again decreased from afternoon to evening. The corresponding value of ambient temperature with peak solar insolation was 34.5ºC and that of inside the portable and foldable type solar dryer was 63.3ºC at 12:30 hrs (Fig.5). The atmospheric relative humidity varied from 61.3 per cent to 87.7 per cent at 12:30 and 18:00 hrs respectively while relative humidity inside the portable and foldable type solar dryer varied 53.8 per cent to 87.1 per cent at 12:30 and 18:00 hrs respectively (Fig. 6).

The moisture content of 6 mm thickness Aonla pieces which were treated with sugar reduced from 281.67 per cent (db) to 29.93 per cent (db) in 30 hrs. While moisture content of Aonla pieces which were without sugar reduced from 718.33 per cent (db) to 58.55 per cent (db) in 600 minutes (Fig. 8). The drying rate of Aonla pieces which were with sugar and without sugar had its peak value 1.41 and 1.67 g water / g dry matter / h respectively during drying time interval of 8.30 to 9.30 of the day i.e. within 1 to 2 hrs from the period of starting of the drying (Fig.7).

In load test of dryer, aonla pieces required more time for drying in open condition due to lower temperature and more humidity's than solar dryer. Use of dryer for drying aonla candy was helpful to remove moisture rapidly as compared to open sun drying and it also give better colour than dried under open sun. Drying efficiency and collection efficiency depends on the removal of moisture from wet aonla pieces and hence maximum drying efficiency and collection efficiency was found as dryer was airtight from all side.

The moisture content showed decreasing trend shown in Fig.8 and trend of variation of moisture ratio against drying time is shown in Fig.9. The drying rate showed of trend descending order after attaining the peak value for Aonla candy samples. It was observed that the reduction in moisture content was high at the beginning and reduced gradually with drying time for Aonla candy.

Moisture reduction study during open sun drying of Aonla Candy in winter season.

The moisture content of 6 mm thickness sugar treated aonla pieces in open sun drying was reduced from 281.67 per cent (db) to 49.68 per cent (db) in 30 hrs. While moisture content for aonla pieces not treated with sugar reduced from 718.33 per cent to 60.61 per cent in 30 hrs. (Fig.11). The peak drying rate observed for sugar treated aonla pieces was 2.20 g water/g dry matter / h during drying time interval of 8:00 to 9:30 of the day and that for aonla pieces without sugar was 2.64 g water / g dry matter / h during drying time interval of 8:00 to 9:30 of the day (Fig.10). The moisture content showed decreasing trend shown in Fig. 9 and trend of variation of moisture ratio against drying time is shown in Fig.12. It was also observed that drying time was reduced for portable and foldable type solar drying as temperature inside portable and foldable type solar dryer was 10-15^{o}C higher than atmospheric temperature.

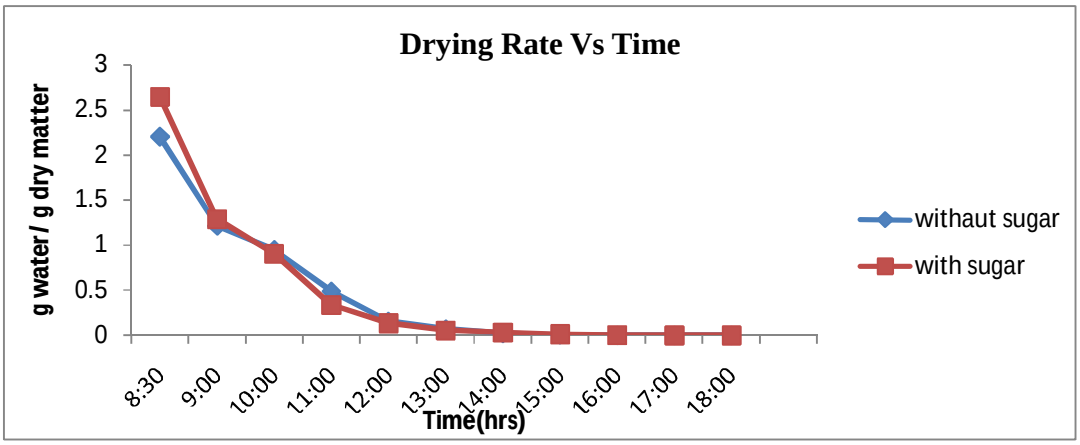


Fig. 10 Drying rate for open sun drying in winter season.

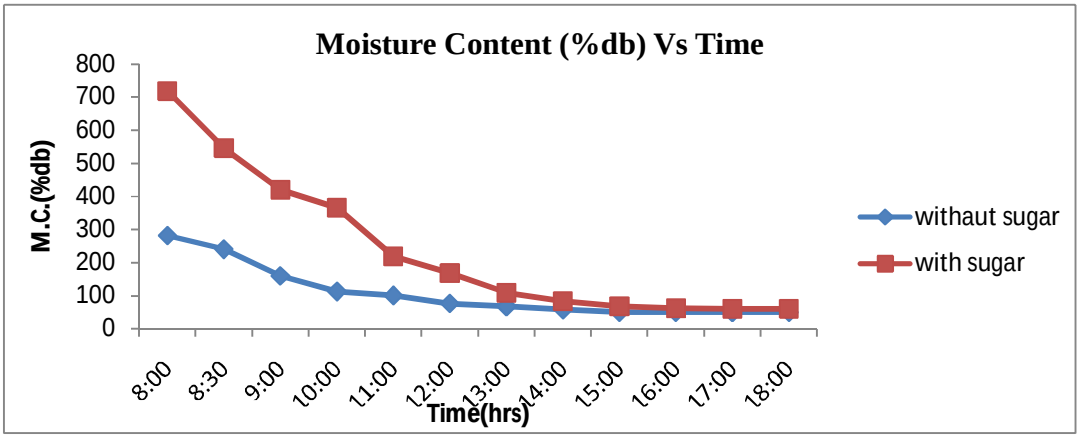


Fig. 11 Moisture content reduction for open sun drying in winter season.

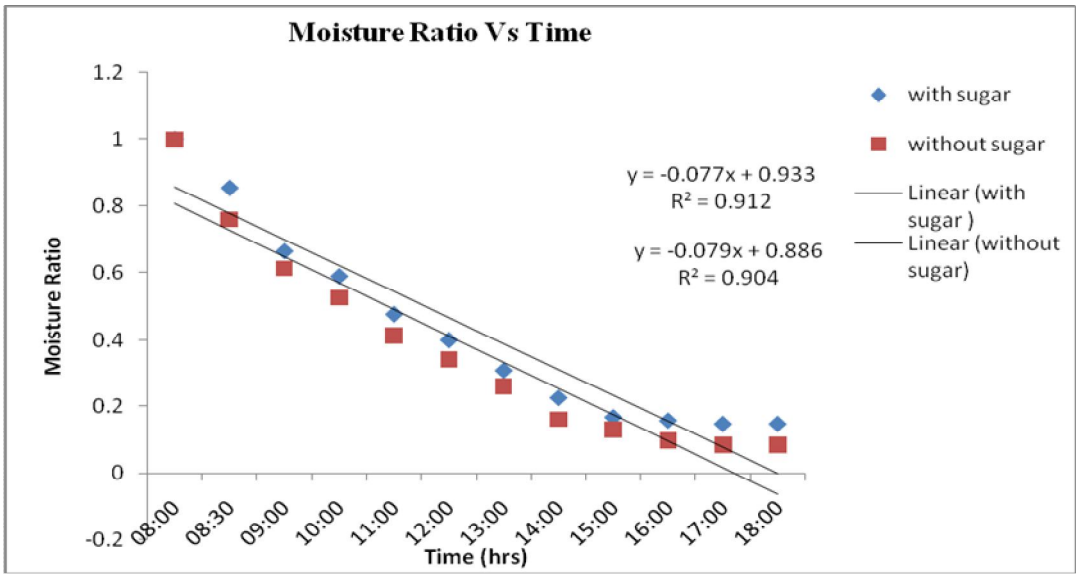


Fig. 12 Moisture ratio variation for open sun drying in winter season.

Moisture reduction study during load test for drying of Vegetables (Spinach, Fenugreek, Cauliflower and Cabbage) under portable and foldable type solar dryer in summer season season.

The different vegetables like Spinach, Fenugreek, Cauliflower and Cabbage were dried in portable solar dryer. The vegetables were cut in small pieces/leaves were treated with two per cent salt solution. Various drying parameters like solar insolation, atmospheric temperature and atmospheric relative humidity with respect to drying time were observed and compared with the parameters inside the D-type portable folding type solar dryer.

As the temperature inside the D-type portable folding type solar dryer increased the relative humidity decreased. Solar insolation increased from morning to afternoon and attained peak value 620 W/m^2 at 12:30 hrs and 624 W/m^2 at 12:30 on fist day and second day respectively again decreased from afternoon to evening. The corresponding value of ambient temperature with peak solar insolation was 48.3^oC at 13:30 hrs and 47.9^oC at 12:30 hrs on first day and second day respectively and that of inside the D-type portable folding type solar dryer was 71.8 ^oC at 13:00 hrs and 71.7 ^oC at 12:00 on first day and second day respectively (Fig.13 & Fig.14).

The ambient relative humidity varied from 35.7 per cent to 53.1 per cent at 13:30 and 18:00 hrs and 35.2 per cent to 54.0 per cent at 13:30 and 18:00 hrs on first and second day respectively while relative humidity inside the D-type portable folding type solar dryer varied 16.2 per cent to 33.0 per cent at 12:00 and 18:00 hrs and 23.5 per cent to 53.2 per cent at 12:00 and 18:00 hrs on first and second day respectively (Fig.15 & Fig.16).

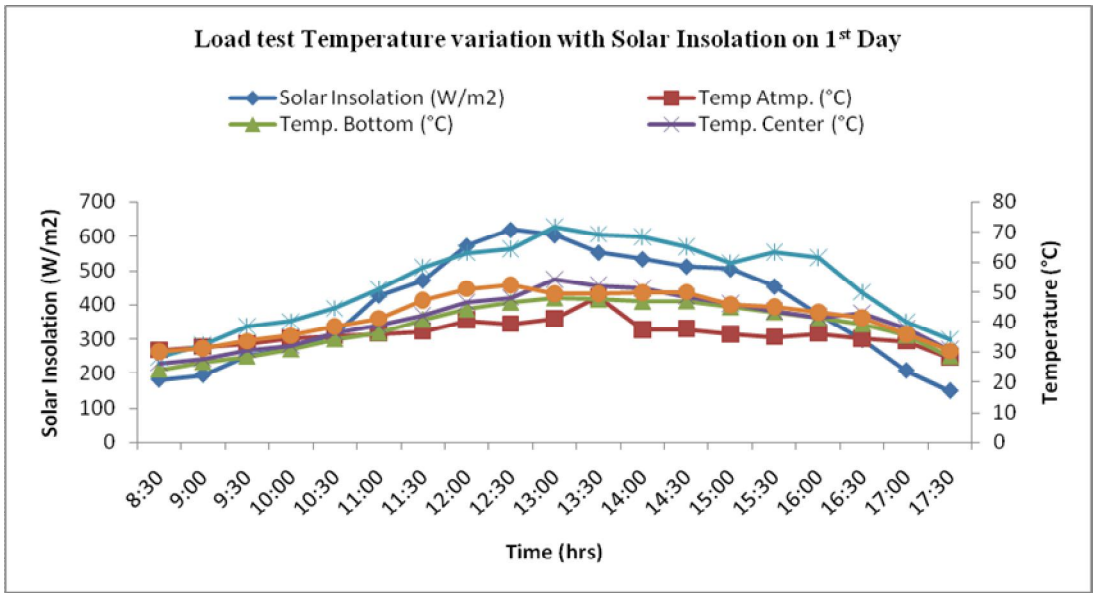


Fig.13 Load test Temperature variation with Solar Insolation on 1st Day in summer season.

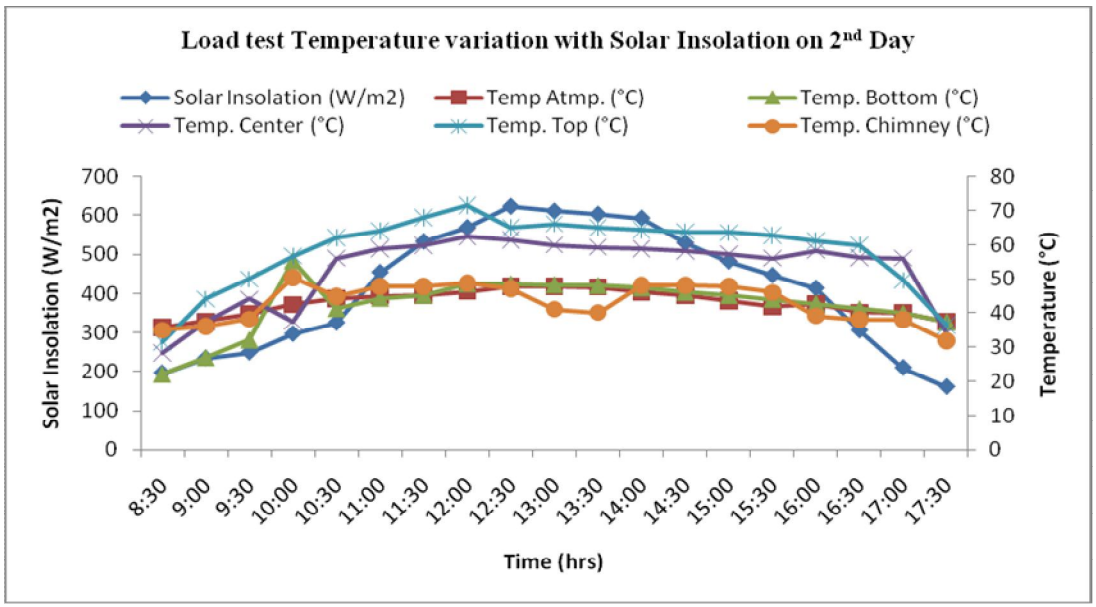


Fig.14 Load test Temperature variation with Solar Insolation on 2nd Day in summer season.

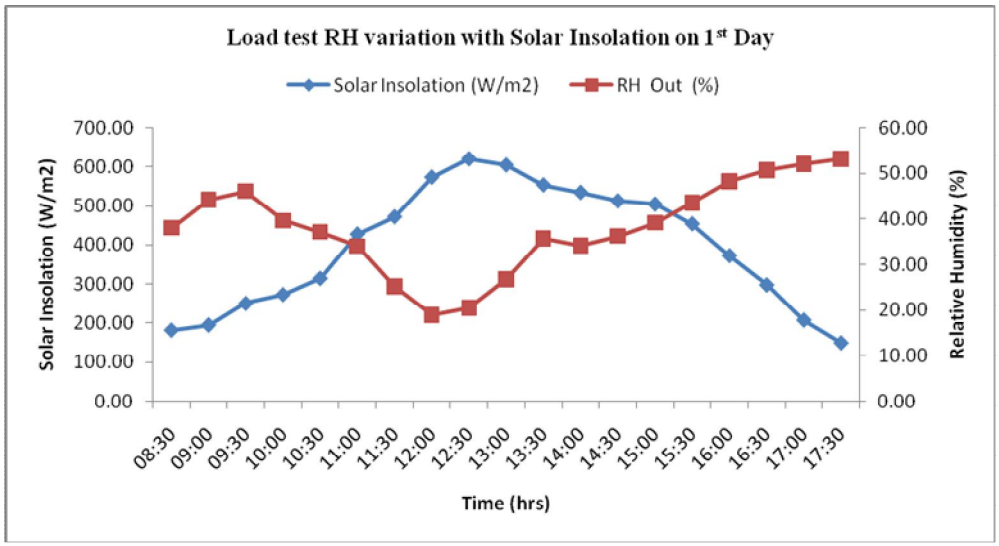


Fig.15 Load test RH variation with Solar Insolation on 1st Day in summer season.

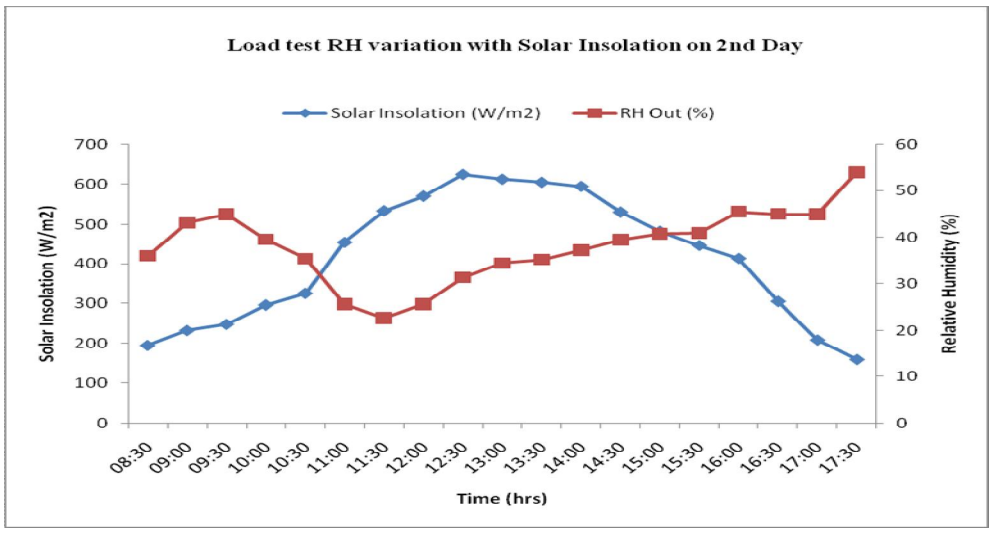


Fig.16 Load test RH variation with Solar Insolation on 2nd Day in summer season.

Moisture reduction study was carried out for the vegetables like Spinach, Fenugreek, Cauliflower and Cabbage, small pieces/leaves of which were treated with salt solution. The moisture content of Spinach leaves reduced from 84.50 per cent (wb) to 28.17 per cent (wb) in 510 minutes. While the moisture content of Fenugreek leaves reduced from 69.50 per cent (wb) to 13.00 per cent (wb) in 480 minutes. While the moisture content of Cauliflower pieces reduced from 68.50 per cent (wb) to 18.90 per cent (wb) in 780 minutes and the moisture content of Cabbage pieces reduced from 81.50 per cent (wb) to 17.81 per cent (wb) in 720 minutes (Fig.17).

The vegetables pieces required more time for sun drying in open condition than in solar dryer due to lower temperature and higher humidity and vice versa in solar drying conditions. Use of solar dryer for drying vegetables was helpful to remove moisture rapidly as compared to open sun drying and it retains colour as compaired to dried under open sun. Drying efficiency and collection efficiency depends on the removal of moisture from wet vegetables pieces and hence maximum drying efficiency and collection efficiency was found as dryer was airtight from all side. The moisture content showed decreasing trend shown in Fig.17. It was observed that the reduction in moisture content was high at the beginning and reduced gradually with drying time for different vegetables.

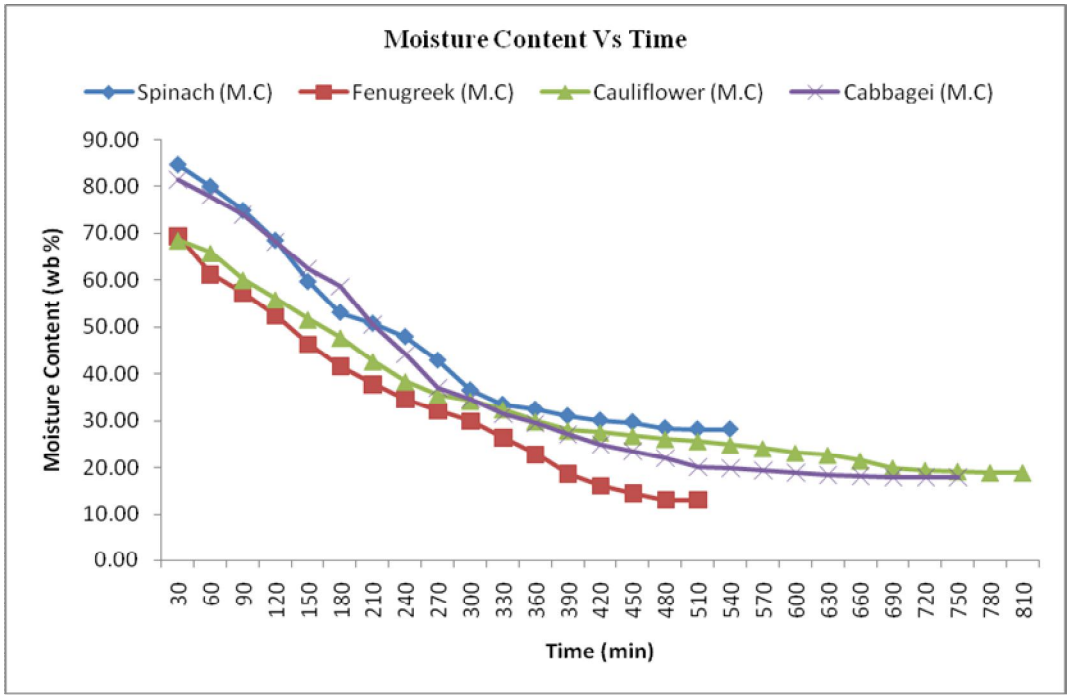


Fig.17 Moisture Content reduction for portable and foldable type solar dryer in summer season.

Moisture reduction study during open sun drying of Vegetables (Spinach, Fenugreek, Cauliflower and Cabbage)

Moisture reduction study was carried for vegetables Spinach, Fenugreek, Cauliflower and Cabbage small pieces which were treated with two per cent salt solution. The moisture content of Spinach leaves in open sun drying was reduced from 84.50 per cent (wb) to 28.00 per cent (wb) in 630 minutes. While the moisture content of

Fenugreek leaves in open sun drying was reduced from 69.50 per cent (wb) to 13.60 per cent (wb) in 750 minutes. The moisture content of Cauliflower pieces in open sun drying was reduced from 68.50 per cent (wb) to 18.00 per cent (wb) in 840 minutes. While the moisture content of Cabbage pieces in open sun drying was reduced from 81.50 per cent (wb) to 17.00 per cent (wb) in 870 minutes. The moisture content showed decreasing trend shown in Fig.18. It was also observed that drying time was reduced for portable and folding type solar drying as temperature inside portable and folding type solar dryer was 15-20 ^{o}C higher than atmospheric temperature.

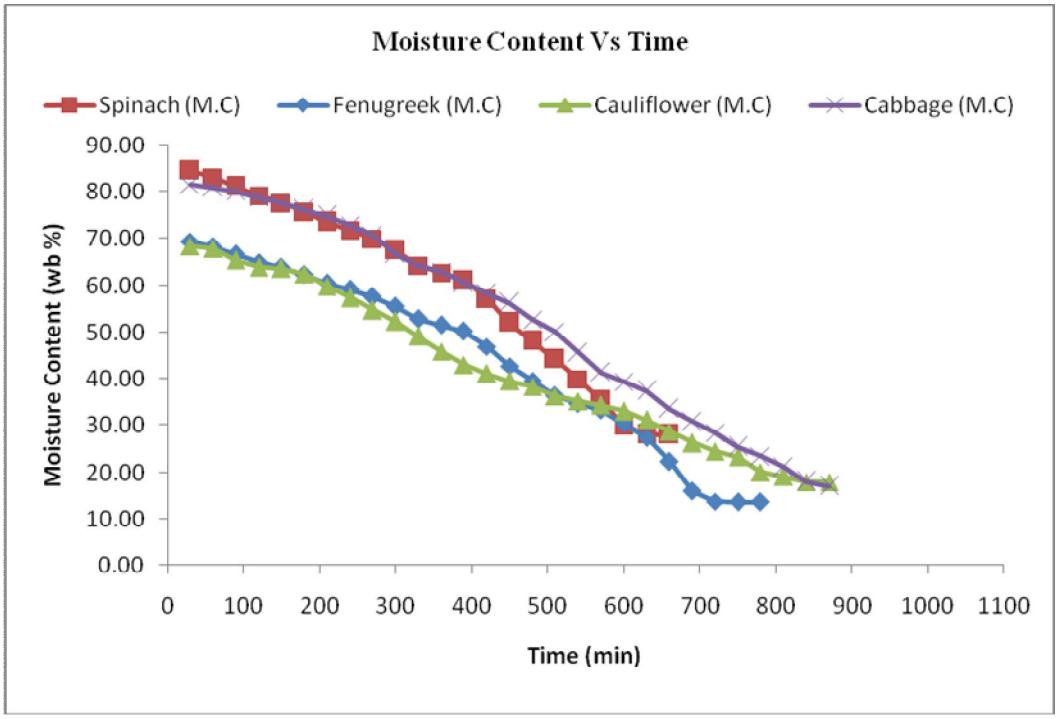


Fig. 18 Moisture Content reduction for open sun drying in summer season

Results:

Based on the design conditions and assumptions, D-type portable folding type of solar dryer was designed, fabricated and performance evaluation was tested in both seasons winter and summer. The temperature attained inside the D-type portable folding type of solar dryer was 15^{o}C-20^{o}C higher than the atmospheric temperature. Anola pieces and vegetables (Spinach, Fenugreek, Cauliflower and Cabbage) were dried in solar dryer.Use of solar drier leads to considerable reduction of drying time in comparison to open sun drying.The losses due to animals, birds can be avoided, similarly the losses due to high wind speed are avoided.

10. Conclusion:

The conclusions drawn from experimental study are as follows,

- The portable and foldable type solar dryer was suitable for drying of products.
- The newly fabricated portable and foldable type solar dryer was suitable for drying of aonla with low cost, that is 1960/-
- The use of solar dryer lead to considerable reduction of drying time (10 hrs) in comparison to open sun drying.

11. Recommendation:

DBSKKV developed portable folding type solar dryer is recommended for drying of agricultural products.

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