Performance Analysis of Solar Drying System for Guntur Chili

T.Bhanu Prakash
M.Tech student, Department of Mechanical Engineering
K L University, Vaddeswaram, Guntur, India.

G. Satyanarayana
Department of mechanical engineering
K L University, Vaddeswaram, Guntur, India.

Abstract: This study is concerned with performance analysis of solar drying system for Guntur red chili. Chili was dried to final moisture content of 9 % w.b from 80% w.b in 24 h using this system. In this study energy analysis was carried out to estimate the heat gain rate for the collector 380 w. The efficiencies of the solar collector 71.4%, drying system 42.18%, at the solar radiation of 950 w/m^2 and a mass flow rate of 0.01 kg/sec. Open sun drying system chili was dried to final moisture content of 9 % w.b from 80% w.b in 56 h using this system.

Keywords: solar drying system, Open sun drying system, w.b.

I. INTRODUCTION

Chili is traditionally dried directly under the open sun. Open sun drying requires a large open space and long drying times. Although this traditional method requires only a small investment, open sun drying is highly dependent on the availability of sunshine and is susceptible to contamination from foreign materials (dust, sand and clay) as well as insect and fungal infestations, which thrive in moist conditions. Such contaminations render the products unusable. Most agricultural and marine products require drying to preserve the quality of the final product, but open sun drying results in low-quality products. Therefore, solar drying has become one of the most attractive and promising applications of solar energy systems as an alternative to open sun drying. Several studies specifically investigated solar drying systems for red chili.

II. AIM OF THE STUDY

For the analysis of the present study Guntur mirchi is taken into consideration. Guntur chillis are a group of cultivars originating in Guntur District, Andhra Pradesh, India. They are exported to Asia, Canada, and Europe. The Guntur district is the main producer and exporter of most varieties of Chillies and chili powder in India to countries like Sri Lanka, Bangladesh, Middle East, South Korea, U.K. and USA & Latin America. Chilies have various colours and flavours because of the level of Capsaicin in them. Guntur chilies form an important part of curries and various popular dishes of the state of Andhra Pradesh in India.

- Guntur Sannam - S4 Type is the most famous type among the chilis and has a huge demand throughout the world. It widely grows in Guntur, Warangal, and Khammam districts of Andhra Pradesh. The skin of crushed chili is thick, red and hot. It has its peak harvesting season from December to May. The annual Production of this type is approximately 280,000 tons. It has an ASTA Colour value of 32.11 and Capsaicin Value of 0.226%.
- 273 chili is a common wrinkled chili.
- Other Guntur Chilies are Phatki, Indo-5, Ankur, Roshni, Bedki and Madhubala, and Teja could be too spicy for some people's taste while a few others are used just to add colour to the dish.
- Wonder Hot chilli is the hottest Guntur chili.
- 334 chillis is a premium export-quality chili.
- Teja chili is a fine variety of Guntur chili.

2.1 Guntur Chilli Characteristics

Guntur Sannam chili has specific characteristics that have enabled it to earn international and national acclaim. Sannam chili is generally known to trade as a S4 type chili and is mainly used for its pungency and for the extraction and derivation of capsaicin. The following are characteristics of Guntur Sannam chili:

- The Guntur Sannam chili belongs to Capsicum variety with long fruits (5 to 15 cm. In length) and diameter range from 0.5 to 1.5 cm.
- The chili has thick skin.
- The skin of crushed chili is thick, red and hot.
- The chili is hot and pungent with average pungency of 35,000 to 40,000 SHU.
- The chili is red with ASTA colour value of about 32.11.
- The content of Capsaicin is about 0.226%.
- This chili is rich in vitamin C (185 mg/100 g) and protein (11.98 g/100 g).

2.1.1 Geographical Area of Production

Table :1

District & State	Latitude	Longitude
Guntur, Andhra Pradesh	15.55°N to 16.35°N	79.19°E to 80.36°E
Warangal, Andhra Pradesh	17.30°N to 18.18°N	78.25°E to 80.15°E
Prakasam, Andhra Pradesh	14.57°N to 16.17°N	78.43°E to 80.25°E
Khammam, Andhra Pradesh	16.48°N to 18.18°N	79.30°E to 81.18°E

2.1.2 Grades of Guntur Sannam.

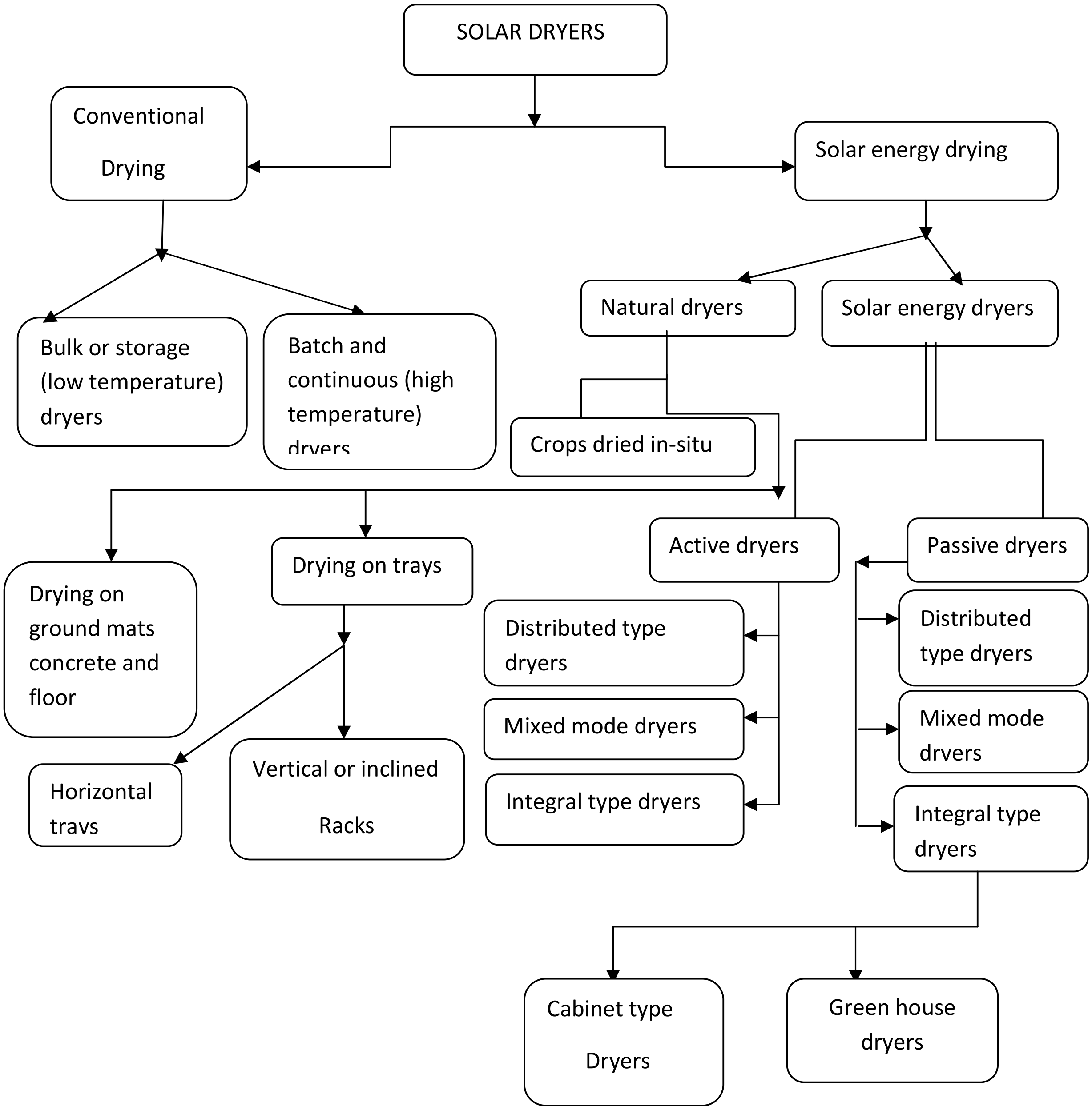
At least 4 grades of Guntur Sannam chilies are known to exist. They are:

- Sannam Special (S.S.): light red in colour, shining, with a length of 5 cm and more.
- Sannam General (S.G.): light red in colour, shining skin, with a length of 3 to 5 cm.
- Sannam Fair (S.F.): which is blackish a dull red in colour with a length of 3 to 5 cm.
- Non Specified (N.S.): This is not a regular grade and is meant to meet specific requirements of the buyers which are not covered under regular grades.

III. CLASSIFICATION OF SOLAR DRYERS

Drying equipment may be classified in several ways. The two most useful classifications are based on
(1). the method of transferring heat to the wet solids.
(2). the handling characteristics and physical properties of the wet material.
The first method of classification reveals differences in dryer design and operation, while the second method is most useful in the selection of a group of dryers for preliminary consideration in a given drying problem. A classification chart of drying equipment on the basis of heat transfer is shown in Figure below. This chart classifies dryers as direct or indirect, with subclasses of continuous or batch wise operation. Solar energy drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilized.

3.1 Classification of Solar Dryers.



IV. WORKING OF SOLAR DRYER

4.1. Indirect solar drying (ISD).

These differ from direct dryers with respect to heat transfer and vapour removal. Figure describes the working principle of indirect solar drying. The crops in these indirect solar dryers are located in trays. The drying cabinet and a separate unit termed as solar collector are used for heating of the entering air into the cabinet. The heated air is allowed to flow through over the wet crop that provides the heat for moisture evaporation by convective heat transfer between the hot air and the wet crop. Drying takes place due to the difference in moisture concentration between the drying air and the air in distributed the crop surface. The advantages of indirect solar drying are:

a) Offers a better control over drying and the product obtained is of better quality than sun drying.

b) Caramelization and localized heat damage do not occur as the crops are protected and opaque to direct radiation.
c) Can be operated at higher temperature, recommended for deep layer drying.
d) Highly recommended for photo-sensitive crops.
e) Have inherent tendency towards greater efficiency than direct solar drying.

They are, however, relatively elaborate structures requiring more capital investment in equipment and incur larger maintenance costs than the direct drying units.

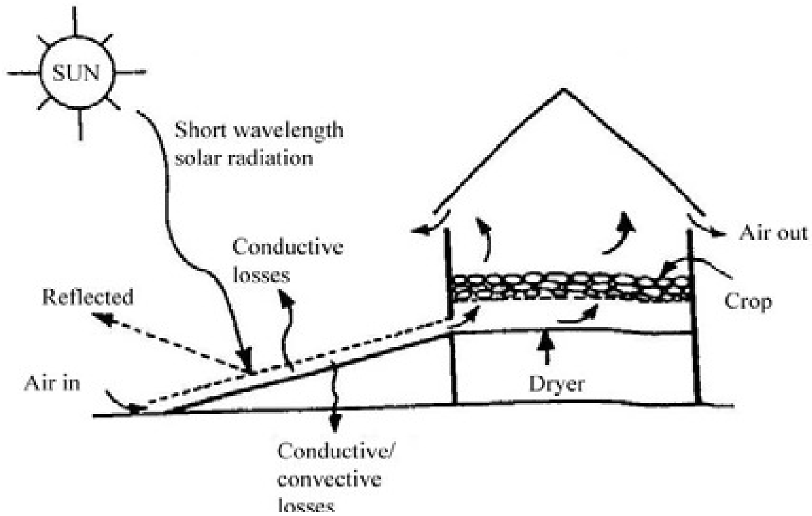


Figure. 1 .Working principle of indirect solar drying system

4.1.2 Selection of solar dryers.

The diversity of food products has introduced many types and combinations of solar dryers to the food industry. The methods of supplying heat and transporting the moisture and the drying product are the basic variations among different types of solar dryers. Table 1.2 enumerates the typical checklist for evaluation and selection for solar dryers.

Table.2 Typical checklist for preliminary evaluation and selection of solar dryers

S.No	Parameters	Features
1.	Physical features of dryer	• Type, size and shape • Collector area • Drying capacity/loading density (kg/unit tray area) • Tray area and number of trays • Loading/unloading convenience
2	Thermal performance	• Solar insulation • Drying time/drying rate • Dryer/drying efficiency • Drying air temperature and relative humidity • Airflow rate
3	Properties of the material being handled	• Physical characteristics (wet/dry) • Acidity • Corrosiveness • Toxicity • Flammability • Particle size • Abrasiveness

4	Drying characteristics of the material	• Type of moisture (bound, unbound, or both) • Initial moisture content • Final moisture content (maximum) • Permissible drying temperature • Probable drying time for different dryers
5	Flow of material to and from the dryer	• Quantity to be handled per hour • Continuous or batch operation • Process prior to drying • Process subsequent to drying
6	Product qualities	• Shrinkage • Contamination • Uniformity of final moisture content • Decomposition of product • Over-drying • State of subdivision • Appearance • Flavour • Bulk density
7	Recovery problems	• Dust recovery • Solvent recovery
8	Facilities available at site of proposed installation	• Space • Temperature, humidity, and cleanliness of air • Available fuels • Available electric power • Permissible noise, vibration, dust, or heat losses • Source of wet feed • Exhaust-gas outlets
9	Economics	• Cost of dryer • Cost of drying • Payback
10	Other parameters	• Skilled technician and operator requirements, • Safety and reliability • Maintenance

4.1.3 Type of Solar Dryer

On the basis of the mode of drying, e.g. direct or indirect, solar dryers may be classified as passive and active ones: (a) Passive dryers, where crops are dried by direct impingement from the sun's radiation with or without natural air circulation, and (b) Active

Solar dryers, where hot drying air is circulated by means of a ventilator (forced convection).

- Active Solar Drying Systems.
- Indirect-Type Active Solar Drying Systems.

4.1.3.1 Active Solar Drying Systems.

Active solar drying systems are designed incorporating external means, like fans or pumps, for moving the solar energy in the form of heated air from the collector area to the drying beds. Thus all active solar dryer are, by their application, forced convection dryer. A typical active solar dryer depends on solar-energy only for the heat source, while for air circulation uses motorized fans or ventilator. These dryers find major applications in large-scale commercial drying operation. Active solar dryers are known to be suitable for drying higher moisture content foodstuffs such as papaya, kiwi fruits, brinjal, cabbage and cauliflower slices and chilli. A variety of active solar-energy dryers exist which could be classified into either the direct -type, indirect-type or hybrid dryers.

4.1.3.2 Indirect-Type Active Solar Drying Systems

These active dryers as discussed for indirect dryer in section a separate collector and drying unit. They are generally comprised of four basic components viz., a solar air heater, drying chamber, a blower for air circulation and ducting. Due to the separate air heating unit higher temperatures can easily be obtained with a control on air flow rate. However as the efficiency of collector decreases at higher temperature operation, an optimum temperature and airflow rate has to be determined to have a cost effective design. While most solar collectors are made up of metal (mild steel) absorbers with appropriate black coatings, materials like tempered glass, air ducting lines, etc. Figure shows below a typical indirect-type active solar dryer. A few designs also employ the recirculation of drying air, which ensures low exhaust air temperature and thereby efficient use of energy. A system employing partial air- circulation, in a metal-tube solar collector. The efficiency of the indirect- type active solar dryer also depends on the location of the fan, though not so significantly in small batches. The prime objective of the fan is to maintain a desired flow-rate in the drying cabinet causing uniform evaporation of moisture from the wet material and in the collector is the collection of heat maintaining a negative pressure, reducing the heat losses. Figure shows the role of the fan in a typical continuous flow in an active solar dryer.

V. SOLAR COLLECTOR DESIGN.

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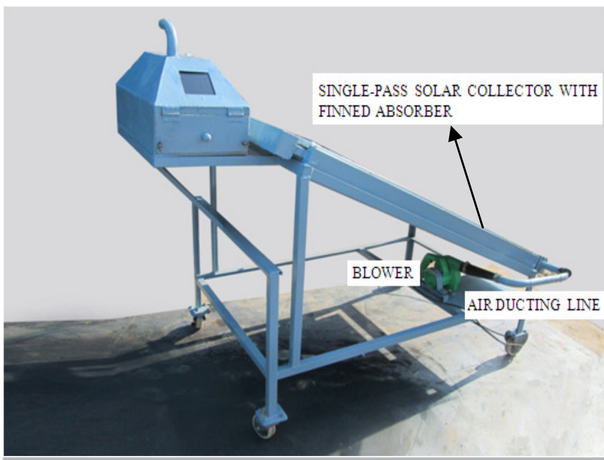

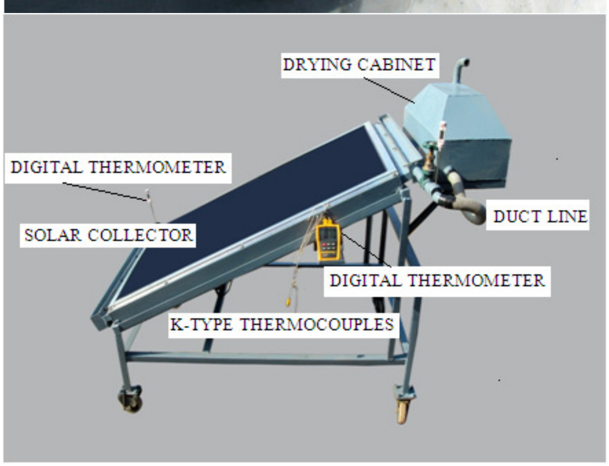

Figure: 2(a) .The schematic of solar drying system. Figure: 2(b) .The schematic of solar drying system.

Samples of chili (Guntur Sannam - S4) were obtained from the farm of Guntur; a total of 1 kg of fresh red chili was used in each experiment. About 10 milligrams of red chili paste were taken and dried in a Bra Bender at a temperature of 130 ± 1 ^{0}C. The initial and final masses of the red chili were recorded using an electronic balance. The procedure was repeated at 0.5 h intervals until the end of the drying process. The average moisture content was 80% (w.b).

The solar drying system consists of a finned single-pass solar collector, a blower, and a flat bed drying chamber. The drying system is classified as a forced convection indirect type. A schematic diagram of the solar dryer is shown in Figure 1(a), 1(b). The width and length of the collector are 0.73 and 1.3 m, respectively. The total area of the collector is 0.95 m^2. The collector has a glass cover, and the sides are insulated and painted black on a mild steel absorber plate. The channel depth is 2.5 cm. The bottom and sides of the collector are insulated with 5.08 cm thick glass wool to minimize heat losses. Air initially enters the collector through the finned absorber plate. The drying chamber is 0.096 m in length, 0.1524 m in width, and 0.3048 m in height.

The drying process was conducted from 9:30 AM to 5:30 PM. The solar dryer was shut down at night. The drying process was continued until the next day, and the process was repeated until the required equilibrium moisture content was reached. For the experiments, the solar dryer was loaded to its full capacity of1 kg of red chili, which was divided and equally distributed on single tray. The red chili was also placed in a small tray positioned at the center of the dryer to determine the moisture loss by using a CS 2000 (Ohaus Compact Scales) digital electronic balance. The balance has an accuracy of 0.1 g. The air temperature (ambient, collector inlet, and collector outlet temperatures), radiation intensity, and air velocity were measured. The air temperatures before entering, inside, and outside the dryer chamber were also measured. An air flow Tes 1340 Hot Wire Anemometer was used to determine the air flow velocity in the solar collector. k -type thermocouples and digital thermometers were used.

VI. PERFORMANCES ANALYSES OF SOLAR COLLECTOR CALCULATION

6.1 Input parameters

The flat collector consists of absorber, insulation, glass plate, fin specifications. The properties of these components are;

6.1 (a) Absorber.

Material = mild steel (20 gauge C.R sheet),

Thickness of the sheet = 0.9 mm.

Dimensions of the absorber plate = 1300 mm* 730mm* 0.9mm.

Thermal conductivity k = 40 w/ m-^{0}k.

Absorber plate coating = black paint

Length of collector (L) = 1350 mm.

Width of collector (W) =780 mm.

Length of absorber plate (l) =1300 mm.

Width of absorber plate (w) = 730 mm.

Air inlet temperature (T_{fi}) = 50 ℃

Ambient temperature T_a = 30^{0}C (308 ^{0}k).

Absorber plate temperature T_{ab} = 70 ^{0}C (343 ^{0}k).

6.1 (b) Insulation.

Material = glass wool slab.

Glass wool Thickness (T_g) = 50mm.

Glass wool Thermal conductivity (k_g) = 0.03 W/ m- ^{0}k.

6.1 (c) Glass plate

Number of glass plate N =1

Glass plate thickness = 4mm

Glass plate dimensions (L*W*T) = 1350mm*780mm* 4mm .

Glass emissivity ϵ_g = 0.88.

The assumed wind speed v= 3 m^2/sec

6.1 (d) Fin specifications.

Material = mild steel (20 gauge C.R sheet),

Fin thickness= 0.9mm.

Fin height =15mm.

Center to center distance between fins = 50mm.

Spacing between absorber and bottom plate = 25mm.

6.1 (d) some other properties.

Solar flux incident on the collector face---------------- 950 w/m^2

Thermal diffusivity τ_α = 0.85

ε_p= emissivity of the absorber plate surface. ----------- 0.95

ε_b= emissivity of the bottom plate surface. ------------- 0.95

The mean fluid temperature of $60^0$for the purpose of evaluating the properties of air, we have

Air density ρ =1.060 kg/ m^3

Specific heat C_p =1.005 k j/kg-^{0}k

Air thermal conductivity K= 0.0290 w/ m-^{0}k

Air velocity V = 18.97 * 10^{-6} m^2/s.

6.2 Mathematical equations

"DITTUS – BOELTER" equation is applicable to solar collector design:

Clearance to spacing ratio (L+ L_f) / (WL- δ_f) is less than one.

The spacing to fin height ratio (W- δ_f) /$L_{f.}$ is greater than one.

These constraints are usually satisfied in practice.

The Nusselt number is = Nu= 0.023 *$Re^{0.8}$ * $Pr^{0.4}$

Where the characteristic dimension used in the definitions of Nu and Re is the equivalent diameter d_e given by

$$\text{Equivalent diameter } d_e = \frac{4\text{* cross –sectional area of a fin channel}}{\text{Wetted perimeter of a fin channel}}$$

$$d_e = \frac{4(WL- \delta_f Lf)}{2\ (WL+ L_f)} \qquad (1)$$

Where;

W= fin centre to centre distance

δ_{f} = fin thickness

L = Spacing between absorber and bottom plate

δ_{f} = fin height.

Clearance to spacing ratio = $(L + L_f) / (WL - \delta_f)$. (2)

Spacing to fin height ratio = $(W - \delta_f) / L_f$ (3)

Average air velocity (m) = $\rho VA * n$ (4)

.Re = inertia force/ viscous force. Where (Re = Reynolds number).

$$Re = V\, d_e / \nu \quad (5)$$

The Nusselt number is = $Nu = 0.023 * Re^{0.8} * Pr^{0.4}$ (6)

$$Nu = 0.023 * 3730^{0.8} * 0.696^{0.4}$$

$$h_{fp} = h_{ff} = h_{fb} = Nu * k / d_e \quad (7)$$

Where, h_{fp} = Connective heat transfer coefficient between the absorber plate and air stream.

h_{ff} = Connective heat transfer coefficient between the fin surface and air stream.

h_{fb} = Connective heat transfer coefficient between the bottom plate and air stream.

h_r =equivalent radioactive heat transfer coefficient.

h_e = effective heat transfer coefficient.

Φ_f = fin effectiveness.

$$\Phi_f = \tanh mL_f / mL_f. \quad (8)$$

The effective heat transfer coefficient equation:

$$h_e = h_{fp} \left(1 + 2 * L_f * \Phi_f * h_{ff} / w\, h_{fp} \quad + hr\right) * \left(h_{fp} / \; h_r + h_{fp}\right) \quad (9)$$

Where, $h_{ff} = h_{fp} = h_{fb}$

$$h_e = h_{fp} \left(1 + 2 * L_f * \Phi_f / w \quad + hr\right) \quad * \left(h_{fp} / \; h_r + h_{fp} \right) \quad (10)$$

$$h_r = 4\left[\sigma\, T_{av}^{3} / (1/ \varepsilon_p + 1/ \varepsilon_b - 1) \right] \quad (11)$$

Where, T_{av} = average ambient temperature.

6.2 (A) Collector Overall Loss Coefficient.

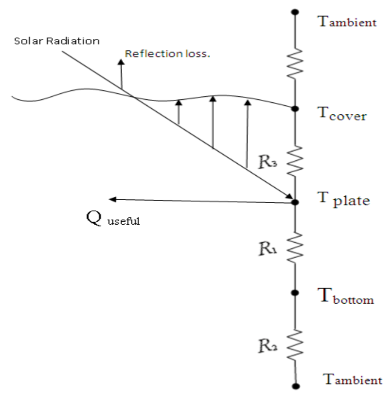

Figure: 3 (a). The thermal net work for the proposed flat plate collector is shown below.

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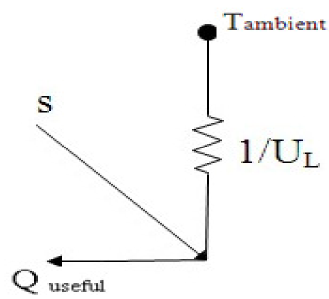

Figure: 3 (b) The equivalent thermal net work

The overall loss coefficient equation (U_L) $=U_b+ U_{t.}$

Where, U_t =Top loss coefficient.

U_b = Bottom loss coefficient.

The Bottom loss coefficient equation.

$$U_b = \frac{\text{glass wool thermal conductivity } (k_g)}{\text{Glass wool thickness } (T_g)} \quad (12)$$

The top loss coefficient suggested (^{0}k), following the basic procedure of "HOTEL and WORT'Z" is given by

$$U_t = \left\{ \frac{N}{[(344/T_p)(T_p - T_a)/(N+f)]^{0.31}} + [1/h_w] \right\}^{-1} +$$

$$\left\{ \frac{\sigma}{(T_p - T_a)\,(T_p^2 - T_a^2)} \right.$$

$$[\varepsilon_p + 0.0425\,N\,(1-\varepsilon_p)]^{-1} + [(2N + f - 1)/\,\varepsilon_g] - N$$

(13)

Where, h_w = wind transfer coefficient

$h_w = 5.5+3.8 * V$

f= (1.0 - 0.04 h_w + 5.0*10^-4* $h_w^{2)}$ *(1+0.058N). (15)

Top loss coefficient modified equitation. $U_{t.}$

The overall loss coefficient equation (U_L) =U_b+ $U_{t.}$

Collector efficiency factor equation (F') = $(1+ (U_L / h_{e)})^{-1}$ (16)

Collector heat removal factor equation;

If relates the actual energy gain of a collector to the use full energy gain if the whole collector surface where at the air inlet temperature. The use full energy gain is expressed as;

Collector heat removal factor equation $F_R = m{*}c_p / U_L A_P\,[1\text{-EXP}\,\{-(F'\,U_L\,A_P) / (mC_P)\}]$ (17)

Heat gain rate for the collector (equation q_u) = $F_R\,A_P\,[(S{*}\,\varepsilon_\alpha) - U_L\,(T_{fi} - T_a)]$. (18)

$$q_u / S\,A_P = F_R\,[(\varepsilon_\alpha) - F_R\,U_L\,(\Delta T/S)].$$

Instantaneous efficiency equation $\eta = F_R\,[(\varepsilon_\alpha) - F_R\,U_L\,(\Delta T/S)]$. (19)

$$q_u / S\,A_P = \eta$$

$$q_u = S\,A_P * \eta$$

The air out let temperature is obtained equation;

$$\Rightarrow m{*}Cp * (T_{ao} - T_{ai}) = q_{u.} \quad (20)$$

The Saving in drying time equation is $S = \frac{tos - tsd}{tos} * 100$ (21)

Where; tos =open solar drying time, tsd =solar drying time

Chili water content was estimated on dry basis. Wet matter value of the samples was calculated. The product water content at different drying stages was then expressed according to the following relation:

$X = \frac{m - ms}{m}$ (22)

Where: m_e is the mass of the product water,
X the water content in wet basis,
m the mass of the product
ms the corresponding wet basis.

Table:3 The table results Performance evaluation of solar collector drying system.

Parameter	Value
Initial weight of product (total)	1 kg
Final weight of product (total)	200 grams
Initial moisture content (wet basis)	80%

Final moisture content (wet basis)	9%
Air mass flow rate	0.01 kg/s
Average solar radiation	950 W/m^2
Average ambient temperature	30^0C
Average drying chamber temperature	50^0C
Average ambient relative humidity	65%
Average drying chamber humidity	38%
Drying time	24 h
Blower air volume	3.5 m^3/min
Evaporative capacity	0.01kg/sec
Overall drying efficiency	42.18%
Initial weight of product (total)	1 kg
Clearance to spacing ratio	0.20 (less than one)
Spacing to fin height ratio	3.27 (greater than one)
Equivalent diameter d_e	d_e = 3.8046 cm.
Average air velocity (m)	V= 1.86 m/s.
Reynolds number(Re)	3730
Nusselt number (Nu)	14.326.
Connective heat transfer coefficient between the bottom plate and air stream. (h_{fb})	10.921 w/ m^2-^{o}k
overall loss coefficient U_L	8.66 w/ m^2 – ^0C
Top loss coefficient. U_t	8.06 w/ m^2 – ^0C
Bottom loss coefficient. U_b	0.6 w/ m^2 – ^0C
wind transfer coefficient h_w	17.1 w/ m^2 – ^0C
Collector efficiency factor F'	71.4%
fin effectiveness (Φ_f)	0.956.
Equivalent radioactive heat transfer coefficient. (h_r)	7.598 w/ m^2-^{0}k.
The effective heat transfer coefficient(h_e)	21.658 w/ m^2-^{0}k .
Collector heat removal factor ($F_{R)}$	0.564
Instantaneous efficiency (η)	0.4218 (42.18%).
Heat gain rate for the collector (q_u)	380.273 w
The air out let temperature (T_{ao})	31.871^0C
water content in wet basis %	9%

VII. RESULTS

During the 3days (24 h) experimentation period is conducted from 9:30 AM to 5:30 PM, the daily mean values of the drying chamber air temperature, drying Chamber and solar radiation ranged from 30 ^0C to 57 ^0C, and 180W/m^2 to 950W/m^2. The drying temperature and relative humidity under solar drying continuously varied with increasing drying time. The results revealed that the drying temperature in solar drying was greater than the ambient temperature, where as the relative humidity in this system was lower than the ambient relative humidity. The drying temperature and relative humidity values also significantly differed at 25 ^0C and 45%, respectively, during the 24 h drying period. The efficiency of the collector ranged from 42.18 to 71.4% with an average value of 35 % at a drying air flow rate of 0.01kg/s

7.1 .Solar Cabinet Inlet& Outlet Temperature Plot

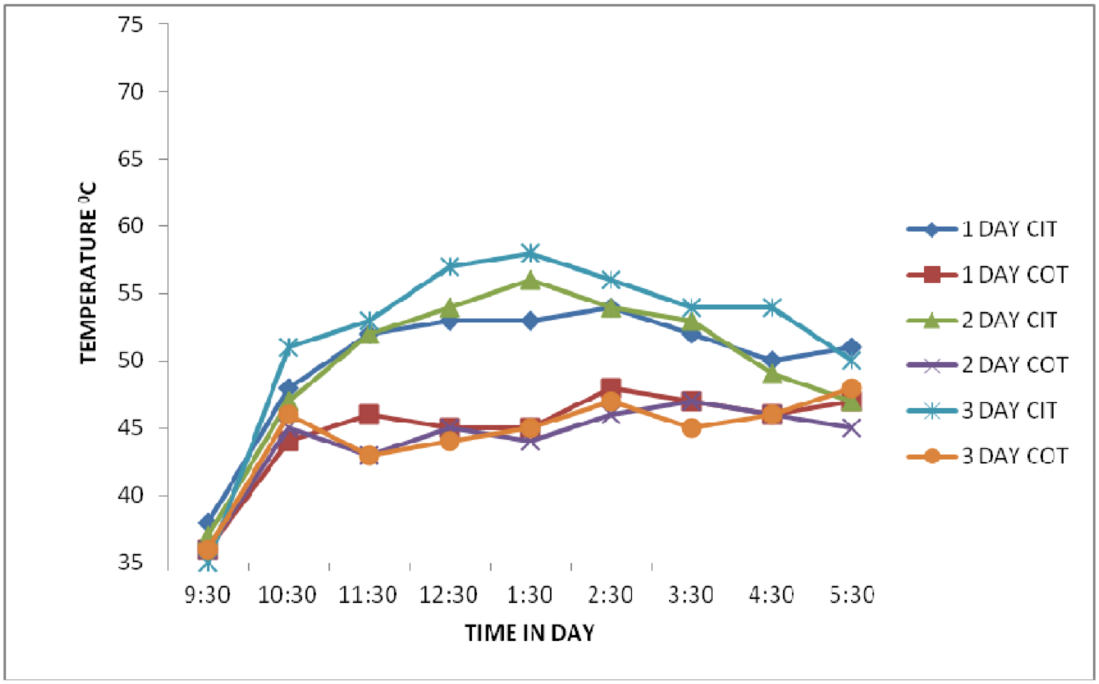

Figure 4 TEMPERATURE Vs TIME IN DAY

The variation of temperature vs. time in day was shown in graph. The graph reveals that temperature increases with increases in time that means sun raises. The graph reveals that temperature decrease with decrease in time that means sun falling. The above chart measuring the every one hour temperature, and weighing to the chilli mass.

7.2. Solar Collector Inlet and Outlet Temperature Plot

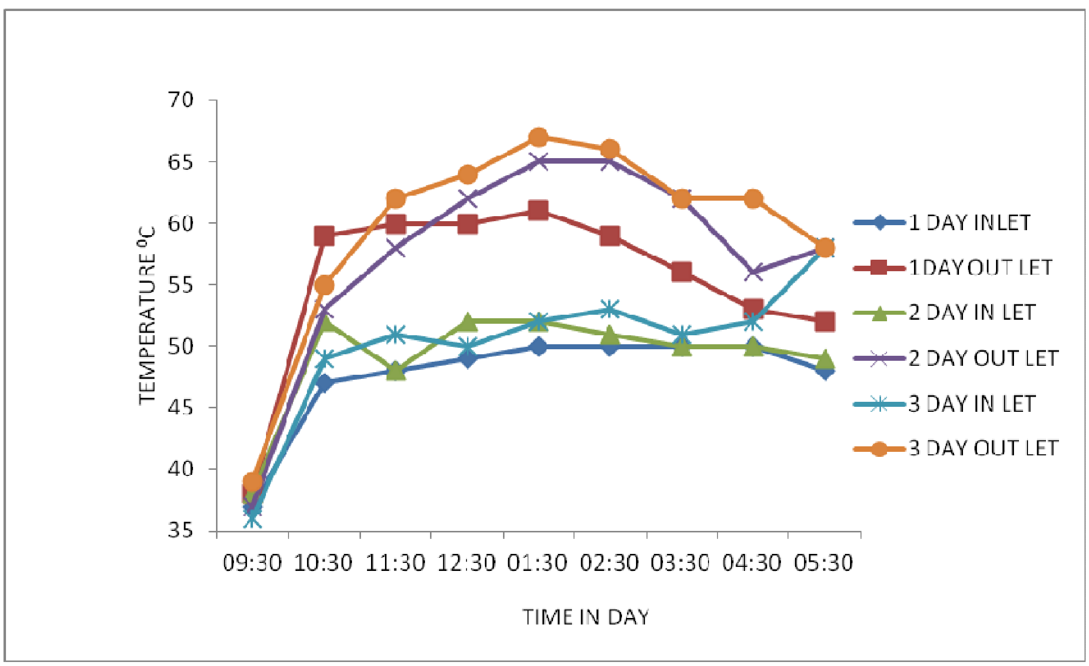

Figure5. TEMPERATURE Vs TIME IN DAY

The variation of temperature vs. time in day was shown in graph. The graph reveals that temperature increases with increases in time that means sun raises. The graph reveals that temperature decrease with decrease in time that means sun falling. The above chart measuring the every one hour temperature of solar collector input and output.

7.3. Solar Drying And Open Sun Drying Rates Plot

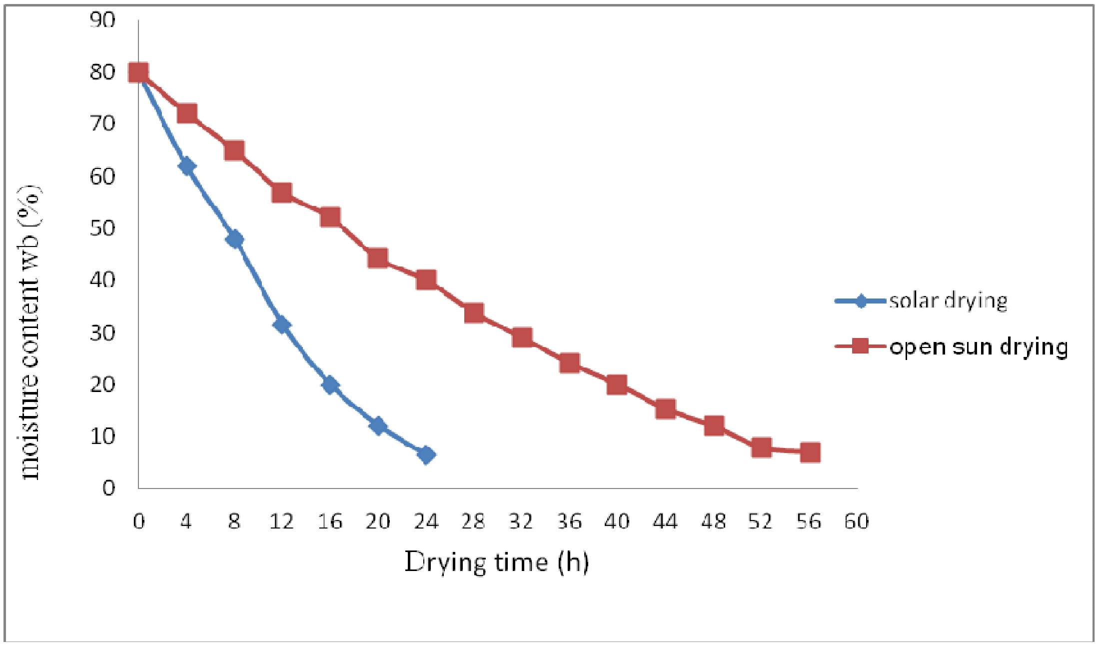

Figure 6. Moisture content (wet basis) variation with dying time.

The above chart will be solar drying and open sun drying rates indicates in the every 4hours. The solar drying in 24 h curve will be plotted and open sun drying 56 h curve will be plotted. The chart will be the x- axis is drying rate in every 4hours and y-axis is moisture content in percentage.

VIII. CONCULUSION

The performances analyses of the solar drying system for chili were performed in this study. Given the results from these analyses, the following remarks may be concluded:

- Drying red chili via solar drying reduced the moisture content from 80% (w.b) to 9% (w.b) in 24 h.
- The solar drying system was compared with open sun drying 57.89% saving in drying time was obtained for the solar drying system .
- The solar radiation of 950 W/m^2 and an air flow rate of 0.01 kg/s. Maximum and minimum collector efficiencies of 71.4%, and 42.18%, respectively, were observed. The drying temperature varied between 30 ^{0}C and 57 ^{0}C with an average of 45 ^{0}C.

IX. NOMENCLATURE

L c Length of collector (mm)

W Width of collector (mm)

l Length of absorber plate (mm)

w Width of absorber plate (mm)

V Air flow rate (m^2/sec)

T_{ai} Air inlet temperature ^{0}C

T_a Ambient temperature ^{0}C

T_{abp} Absorber plate temperature ^{0}C

k Thermal conductivity w/ m-^{0}k.

ϵ_g Glass emissivity

ε_p emissivity of the absorber plate surface.

ε_b emissivity of the bottom plate surface.

ρ Air density (kg/ m^3)

C_p Specific heat (k j/kg-^{0}k)

W fin centre to centre distance (mm)

δ_f fin thickness (mm)

L Spacing between absorber and bottom plate (mm)

δ_f fin height.(mm)

d_e Equivalent diameter (mm)

Nu Nusselt number

Re Reynolds number

h_{fb} Connective heat transfer coefficient between the bottom plate and air stream. (w/ m^2-^{o}k)

h_r equivalent radioactive heat transfer coefficient. . (w/ m^2-^{o}k)

h_e effective heat transfer coefficient. . (w/ m^2-^{o}k)

Φ_f fin effectiveness.

T_{av} average ambient temperature. ^{0}C

U_L overall loss coefficient w/ m^2 – ^{0}C

U_t Top loss coefficient. w/ m^2 – ^{0}C

U_b Bottom loss coefficient. w/ m^2 – ^{0}C

w.b wet basis %

h_w wind transfer coefficient w/ m^2 – ^{0}C

F' Collector efficiency factor

F_R Collector heat removal factor

q_u Heat gain rate for the collector

η Instantaneous efficiency (%)

T_{ao} air out let temperature ^{0}c

S Saving in drying time (%)

t_{os} Open solar drying time (h)

t_{sd} Solar drying time (h)

x water content in dry basis %

Subscripts:

c collector

a ambient

abs absorber plate

g glass

f fin

L loss

u useful

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