Design And Performance Analysis Of An Indirect Type Solar Dryer

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Abstract: In present era, renewable sources have become popular topics of study for engineering reserach. One such source i.e. solar energy is used in different applications like solar water heating, solar space heating, solar water distillation and solar drying etc. The solar dryer uses solar energy to heat up air coming through the collector and after that hot air passes over the product to remove the moisture, which is beneficial in reducing wastage of agricultural product and helps in preservation of agricultural product. On the basis of limitations of natural sun drying e.g. exposure to direct sunlight, liability to pests, lack of proper monitoring and the high cost of the mechanical dryer, a solar dryer is therefore developed to overcome this limitation. Current endevour is focused on fabrication, designing and evaluation of thermal efficiency of an indirect type solar dryer. In the dryer, the heated air from a separate solar collector is passed through the drying trays on which product is placed to remove the moisture. The performance analysis is based on the experimental data collection and calculations with reference to thermal performance calculations, overall loss coefficient and heat correlations. So, different mathematical equations for calculation of thermal efficiency have been used. Experimental results revealed that the temperatures inside the dryer and solar collector were much higher than the ambient temperature during the drying period. The experimental thermal efficiency of the collector is around 43 % and the calculated thermal efficiency is around 51 %. The overall efficiency calculated by mathematical equations is around 44 %, while experimental overall efficiency is around 35%. The less value of experimental efficiency is due to more losses involved in the system in comparison to the losses considered in theortical process.

Keywords: Design; Indirect solar dryer; Performance analysis; Thermal efficiency; Overall efficiency.

I. INTRODUCTION

Fast increase in population and depeltion of fossil fuels has summoned the requirement of alternate energy sources globally. India is a developing nation which require both economy and energy. India has almost 300 sunny days in a year with theoretically 5,000 trillion kWh per year which exceeds than energy output from thermal power plants. Since majority of the population lives in rural areas in India, there is scope for solar energy being captured in these areas **[1]**. Solar energy can be directly supplied for farm energy requirements like crop and grain drying. The simplest method to allow dry crops to naturally in the field, or to spread grain and fruit out in the sun after harvesting. Sophisticated solar dryers protect grain and fruit, reduce losses, dry faster and produce a better quality product than open-air methods. To understand the performance of a solar dryer, research efforts have been given **[2]**. Previous studies have examined the effect of air flow rate, type of convection, type of dryers, energy storage system, type of product, design of collectors etc. on the efficiency of the collectors and overall system. Different mathematical models have also been developed for the performance study of the solar dryer. While working on the solar dryer, mass flow rate and temperature variation plays an important role on the efficiency of the overall system. Papade et al. (2014) reported that latent heat storage is effective in comparison to sensible heat storage. Storage of energy is important for normal working of dryer during night and cloudy weather. PCM's are convenient to storing solar energy **[3]**. Babagana et al. (2012) reported that the drying rates and the drying times for the same amount of several vegetables are less for forced convection **[4]**. Maia et al. (2012) presented a numerical simulation of the airflow inside a hybrid solar-electrical dryer, using a commercial CFD package.

With prescribed temp and velocities, the model predicts the behaviour of the airflow inside the device **[5]**. Boughali et al. (2009) practically tested model of solar dryer for range of mass flow rate. The fraction of electrical and solar energy contribution versus air mass flow rate was investigated **[6]**. Mustayen et al. (2014) reported direct, indirect, mixed mode, active and passive dryers and focused on models that are suitable for producing high quality dried products and discussed the ways to create simple, inexpensive and low cost dryers **[7]**. Jain et al. (2015) observed that solar dryer with phase change materials (PCM) are more efficient with maintained drying temp range. This type of dryer was financially viable with payback period of approx. 2 years **[8]**. Mohajer et al. (2008) reported a new hybrid system which facilitates a dual-purpose solar collector to simultaneously support a dryer system and provide consumptive hot water **[9]**. Shalabya et. al (2014) observed that latent heat storage provides much higher storage density than sensible heat storage, with a smaller temperature difference **[10]**. Chauhan et al. (2014) observed that application of software is very important to predicting the performance of system **[11]**. Kant et. al (2016) concluded that energy storage material is quiet effective for continuously drying in the temp range (40^{o}C-60^{o}C) **[12]**.Singh et. al (2012) developed a steady state mathematical model based on heat balance concept of solar dryer without load is applied to identify the dimensionless parameter called no-load performance index (NLPI) **[13]**. Amjad et. al (2016) performed energy and exergy analyses for an innovative diagonal-batch dryer using potato slices of 5 mm and 8 mm thicknesses at 55 °C and 65 °C. The outcomes of the analysis will provide insights into the optimization of a batch dryer for the maximum retention of quality parameters and energy saving **[14]**. Amer et. al (2016) developed hybrid solar dryer. Drying was also carried out at night with stored heat energy in water which was collected during the time of sun-shine and with electric heaters located at water tank. The efficiency of the solar dryer was raised by recycling about 65% of the drying air in the solar dryer and exhausting a small amount of it outside the dryer **[15]**. The aim of this paper is to design and analyse the performance of an indirect type solar dryer on different time of day (i) by taking suitable dimensions and (ii) by taking different products here overall efficiency is calculated and compared with the theoretical efficiency of the system.

II. DESIGN OF INDIRECT TYPE SOLAR DRYER

(A) Design specifications and assumptions

Solar drying may be classified into direct and indirect solar dryer. In direct solar dryers the air heater contains the grains and solar energy which passes through a transparent cover and is absorbed by the grains. Essentially, the heat required for drying is provided by radiation to the upper layers and subsequent conduction into the grain bed. However, in indirect dryers, solar energy is collected in a separate solar collector (air heater) and the heated air then passes through the grain bed. The objective of this study is to design an indirect mode solar dryer in which the grains are dried by the heated air from the solar collector. The materials used for the construction of the indirect mode solar dryer are cheap and easily obtainable in the local market. Figure 1 shows the main components of the dryer, consisting of the solar collector (air heater), the drying cabinet and drying trays.

(B) Solar dryer components

The solar dryer consists of the solar collector (air heater), the drying cabinet and drying trays:

(a) Collector (Air heater)

The heat absorber (inner box) of the solar air heater was constructed using 2 mm thick aluminium plate, painted black, is mounted in an outer box built from wellseasoned woods. The space between the inner box and outer box is filled with foam material of about 40 mm thickness. The solar collector assembly consists of air flow channel enclosed by transparent cover (glazing). An absorber back plate provides effective air heating because solar radiation that passes through the transparent cover is then absorbed by back-plate. The glazing is a single layer of 4 mm thick transparent glass sheet; it has a surface area of 800 mm by 1300 mm and of transmittance above 0.7 for wave lengths in the rage 0.2 – 2.0 µm and opaque to wave lengths greater than 4.5 µm. The effective area of the collector glazing is 1.04 m^2. One end of the solar collector has an air inlet vent of area 0.042 m^2.

Figure1 Solar collector

(b) The drying cabinet

The drying cabinet together with the structural frame of the dryer was built from well-seasoned woods which could withstand termite and atmospheric attacks as shown in Figure 2. An exhaust fan was provided toward the upper end of the cabinet to facilitate and control the convection flow of air through the dryer. Access door to the drying chamber was also provided at the back of the cabinet. The roof and the two opposite side walls of the cabinet are painted black, which provided additional heating.

Figure 2 Drying chamber

(c) Drying trays

The drying trays are contained inside the drying chamber and were constructed from a double layer of fine chicken wire mesh with a fairly open structure to allow drying air to pass through the food items as shown in Figure 3.

Figure 3 Drying trays

The flat-plate solar collector is always tilted and oriented in such a way that it receives maximum solar radiation during desired season of use. The best stationary orientation is south in northern hemisphere and north in southern hemisphere. Therefore, solar collector in this work is oriented facing south and tilted at 30^0 to the horizontal.

III. DEVICE SPECIFICATIONS

(A) Air velocity meter

It accurately measures air velocity and temperature, calculates flow rate, performs averaging, and can determine minimum and maximum readings. Using sweep mode, it can quickly provide one averaged reading of velocity or volume over a large measurement area. The large vane head automatically averages and dampens velocity and volume readings. The Air velocity meter Model 5725 is shown in Figure 4(a), which includes variable time constant, sampling and statistics functions and data logging capability.

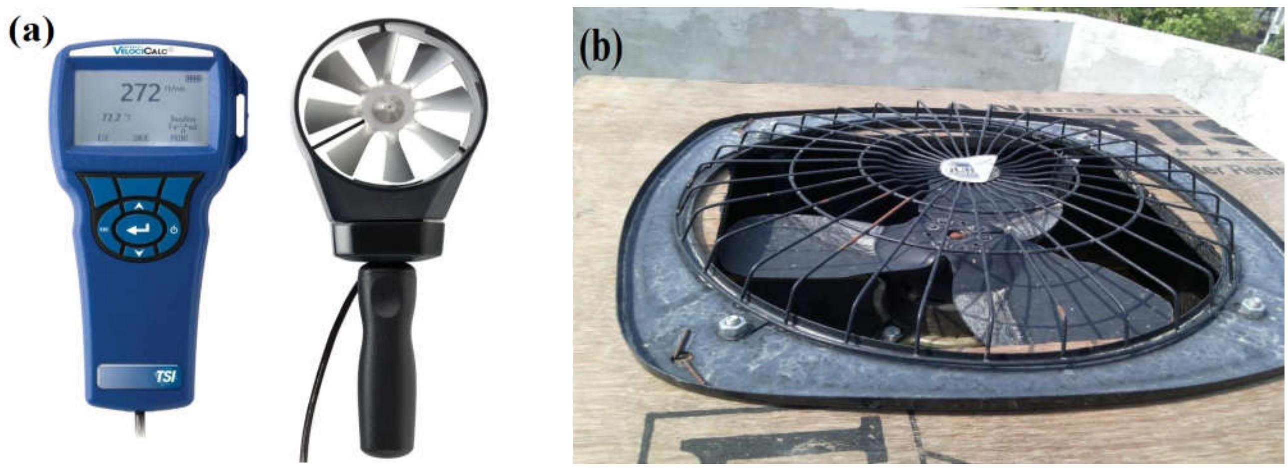

Figure 4 (a) Air velocity meter **(b)** Exhaust fan

(B) Exhaust Fan

Exhaust fan as shown in Figure 4(b) was required to create the pressure gradient inside the dryer so that air with moisture will go outside through the fan and ambient air will enter from the collector inlet.

(C) J-type thermocouple (iron-constantan)

Figure 5 shows J-type thermocouple which has temperature range about −40 °C to +750 °C and has sensitivity of about 50 μV/°C. Three thermocouples were installed, two at the inlet and outlet of the collector, and third one inside the drying chamber for taking the temperature readings.

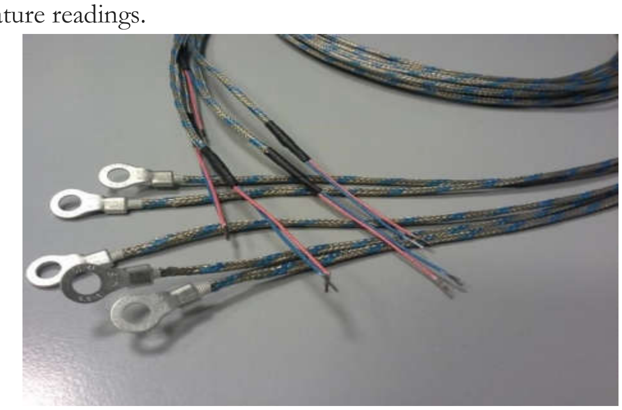

Figure 5 J-type thermocouple

The thermocouples were connected to the temperature indicator shown below, to display all the temperature of the system

IV. MATHEMATICAL MODELS AND FORMULATIONS

(A) Operation of the dryer

The dryer is a passive system in the sense that it has no moving parts. It is energized by the sun rays entering through the collector glazing. The trapping of the rays is enhanced by the inside surfaces of the collector that were painted black and the trapped energy heats the air inside the collector. The green-house effect achieved within the collector drives the air current through the drying chamber. If the vents are open, the hot air rises and escapes through the upper vent in the drying chamber, while cooler air at ambient temperature enters through the lower vent in the collector. Therefore, an air current is maintained, as cooler air at a temperature T_a enters through the lower vents and hot air at a temperature T_e leaves through the upper vent.

When the dryer contains no items to be dried, the incoming air at a temperature T_a has relative humidity H_a and the out-going air at a temperature T_e, has a relative humidity H_e , because $T_e > T_a$ and the dryer contains no item, $H_a > H_e$. Thus there is tendency for the out-going hot air to pick more moisture within the dryer as a result of the difference between H_a and H_e. Therefore, insulation received is principally used in increasing the affinity of the air in the dryer to pick moisture.

(B) Drying mechanism

In the process of drying, heat is necessary to evaporate moisture from the material and a flow of air helps in carrying away the evaporated moisture. There are two basic mechanisms involved in the drying process:

- The migration of moisture from the interior of an individual material to the surface, and
- The evaporation of moisture from the surface to the surrounding air. The drying of a product is a complex heat and mass transfer process which depends on external variables such as temperature, humidity and velocity of the air stream and internal variables which depend on parameters like surface characteristics (rough or smooth surface), chemical composition (sugars, starches, etc.), physical structure (porosity, density, etc.), and size and shape of product.

(a) Basic theory (Formulations)

The energy balance on the absorber is obtained by equating the total heat gained to the total heat loosed by the heat absorber of the solar collector. Therefore,

$$\mathbf{I}_c A_c = Q_u + Q_{cond} + Q_{conv} + Q_R + Q_\rho \quad \text{……………………}(1)$$

Where: I = rate of total radiation incident on the absorber surface (Wm^{-2});

A_c = collector area (m^2);

Q_u = rate of useful energy collected by the air (W);

Q_{cond} = rate of conduction losses from the absorber (W);

Q_{conv}= rate of convective losses from the absorber (W); Q_R = rate of long wave re-radiation from the absorber (W); Q_ϱ = rate of reflection losses from the absorber (W).

The three heat loss terms Q_{cond}, Q_{conv} and Q_R are usually combined into one-term

(Q_L), i.e.,

$$Q_L = Q_{cond} + Q_{conv} + Q_R \quad \text{……………………………………………………………}(2)$$

If τ is the transmittance of the top glazing and it is the total solar radiation incident on the top surface, therefore,

$$I_c A_c = \tau I_T A_c \text{………………………………………………………………………...…}(3)$$

The reflected energy from the absorber is given by the expression:

$$Q_\rho = \rho \tau I_T A_c \text{…………………………………………………………………………………}(4)$$

Where ϱ is the reflection coefficient of the absorber. Substitution of Eqs. (2), (3) and (4) in Eq. (1) yields:

, or

$$\tau I_T A_c = Q_u + Q_L + \rho \tau I_T A_c \quad \text{……………………………………………………………….}(5)$$

$$Q_u = \tau I_T A_c (1 - \rho) - Q_L$$

For an absorber (1 – ϱ) = α and hence,

$$Q_u = \alpha \tau I_T A_c - Q_L,$$

…………………………………………………………………………...…(6)

Where α is solar absorbance. Q_L composed of different convection and radiation parts. It is presented in the following form:

$$\mathbf{Q_L = U_L A_c (T_c - T_a),} \quad \ldots(7)$$

Where: U_L = overall heat transfer coefficient of the absorber ($Wm^{-2}K^{-1}$);

T_c = temperature of the collector absorber (K); T_a = ambient air temperature (K).

U_L is represented in the following form :

$$U_L = U_T + U_B,$$

Where U_T and U_B are top losses and bottom losses respectively and can be represented as:

$$U_T = \left[\frac{N}{\frac{C_a}{T_c}\left[\frac{T_c - T_a}{N+f}\right]^e} + \frac{1}{h_w}\right]^{-1} + \frac{\sigma(T_c + T_a)(T_c{}^2 + T_a{}^2)}{\left[(\epsilon p + 0.00591Nh_w)^{-1} + \frac{[2N + f - 1 + 0.133\epsilon_p]}{\epsilon_g} - N\right]} \quad \ldots(8)$$

Where C_a, f, e and h_w are given by:

$$C_a = 520(1 - 0.00005\beta^2)$$

$$f = (1 + 0.089h_w - 0.1166h_w\epsilon_p)(1 + 0.07866N)$$

$$e = 0.43(1 + \frac{100}{T_c})$$

$$hw = 5.7 + 3.8v \quad \ldots(9)$$

The bottom loss is assumed to take place one dimensionally through the insulation at the bottom. The bottom loss coefficient is given by

$$U_B = \frac{K_s}{L_s} \quad \ldots(10)$$

From Equations (5) and (6) the useful energy gained by the collector is expressed as:

$$Q_u = (\alpha\tau)I_T A_c - U_L A_c (T_c - T_a)$$

Therefore, the energy per unit area (q_u) of the collector is

$$q_u = (\alpha\tau)I_T - U_L(T_c - T_a) \quad \ldots(11)$$

If the heated air leaving the collector is at collector temperature, the heat gained by the air Q_g is:

$$Q_g = m_a \cdot C_{pa}(T_c - T_a), \quad \ldots(12)$$

Where: m_a = mass of air leaving the dryer per unit time (kgs^{-1}); C_{pa} = specific heat capacity of air ($kJkg^{-1}K^{-1}$).

The collector heat removal factor, F_R, is the quantity that relates the actual useful energy gained of a collector, Eq. (6), to the useful gained by the air, Eq. (8). Therefore,

$$F_R = \frac{m_a \cdot c_{pa}(T_c - T_a)}{A_c(\alpha\tau I_T - U_L(T_c - T_a))} \quad \ldots(13)$$

The thermal efficiency of the collector is defined as is given in Eq. (13):

$$\eta_c = \frac{Q_g}{A_c I_T} \quad \ldots(14)$$

(b) Energy balance equation for drying process

The total energy required for drying a given quantity of food items can be estimated using the basic energy balance equation for the evaporation of water:

$$m_w L_v = m_a C_{pa}(T_1 - T_2) \quad \ldots(15)$$

Where:
L_v = latent heat of vaporisation (kJ kg^{-1}) m_w = mass of water evaporated from the food item (kg); m_a = mass of drying air (kg);
T_1 and T_2 = initial and final temperatures of the drying air respectively (K); C_p = Specific heat at constant pressure (kJ $kg^{-1}K^{-1}$).
The mass of water evaporated is calculated from Eq. 14:

$$m_w = \frac{m_i(M_i - M_e)}{(100 - M_e)} \quad (16)$$

Where:
m_i = initial mass of the food item (kg);
M_e = equilibrium moisture content (% dry basis); M_i = initial moisture content (% dry basis).
Average drying rate

$$M_{dr} = \frac{m_w}{T_d} \quad (17)$$

Where:
m_w = mass of water vapour to be evaporated
T_d = drying time
Overall system efficiency

$$\eta_o = \frac{m_w \times L_v}{I_T A_c + P_f} \quad (18)$$

Where:
L_v = latent heat of vaporisation for water vapour (kJ/kg)
P_f = energy consumption of fan (kJ)
During drying, water at the surface of the substance evaporates and water in the inner part migrates to the surface to get evaporated. The ease of this migration depends on the porosity of the substance and the surface area available. Other factors that may enhance quick drying of food items are: high temperature, high wind speed and low relative humidity. In drying grains for future planting, care must be taken not to kill the embryo. In drying items like fish, meat, potato chips, plantain chips etc., excessive heating must also be avoided, as it spoils the texture and quality of the item.

V. THEORETICAL CALCULATIONS AND EXPERIMENTAL RESULTS

Theoretical calculations have been done by assuming different properties of the materials used in the drying system and different types of losses involved. On the other way, temperature observations and mass observation of different products taken at different times and days have been shown. The inlet temperature of the air passing through the collector doesn't vary too much but the outlet temperatures of the collector as well as drying chamber temperature vary with respect to time. In the morning time, the outlet temperature of both units (collector and drying chamber) and the moisture removal rate from the product are comparatively low but, in the noon time the outlet temperature as well as moisture removal rate are higher for the same flow rate of air through the collector.

(A) Theoretical calculations

There will be some losses like collector loss, convective loss, radiation loss etc. in the trough system. Considering these losses, the thermal efficiency of the collector was calculated as follows: From,

$$U_L = U_T + U_B,$$

From equation 8,

$$U_T = \left[\frac{N}{\frac{C_a}{T_c}\left[\frac{T_c - T_a}{N + f}\right]^e} + \frac{1}{h_w} \right]^{-1} + \frac{\sigma(T_c + T_a)(T_c^2 + T_a^2)}{\left[(\epsilon p + 0.00591Nh_w)^{-1} + \frac{[2N + f - 1 + 0.133\epsilon_p]}{\epsilon_g} - N\right]}$$

From equation 9,
C_a = 496.6, e = 0.56522, f = 1.01650006 and h_w=5.700000120
Hence, U_T = 2.770768 W/m²K
From equation 10,
U_B = 1.1 W/m²K
Hence, $U_L = U_T + U_B$ = 3.870768 W/m²K
Now, from equation 8,

$$Q_L = U_L A_c (T_c - T_a)$$

Q_L = 48.4351 W
Useful energy received by collector,

$$Q_u = (\alpha\tau) I_T A_c - U_L A_c (T_c - T_a)$$

Qu = 415.6485 W
Energy gain by the air in the collector,

$$Q_g = m_a \cdot C_{pa} (T_c - T_a),$$

Qg = 340.98 W
Now from equation 14, heat removal factor

$$F_R = \frac{m_a \cdot c_{pa}(T_c - T_a)}{A_c(\alpha\tau I_T - U_L(T_c - T_a))}$$

F_R=0.8203789

From equation (15), collector efficiency

$$\eta_c = \frac{Q_g}{A_c I_T}$$

η_c = 50.29%
Let the mass of the product to be dried= 1500 gram
Drying time = 10 hours
Mass of the product after drying = 600 grams
Mass of water vapour to be removed = 900 gram
Then, overall efficiency

$$\eta_o = \frac{m_w \times L_v}{I_T A_c + P_f}$$

η_o = 43.9203%

(B) Practical observations and graphs

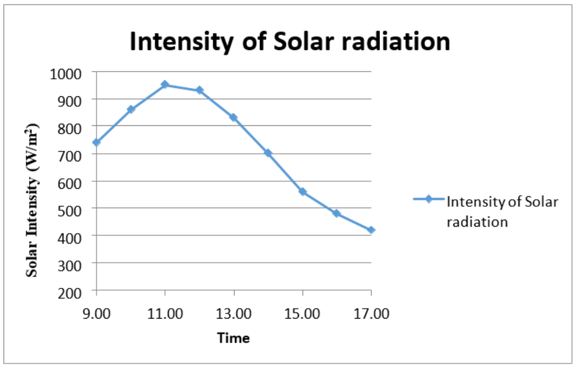

Figure 6 Average variation of solar intensity versus time

Figure 6 show average variation of solar intensity with respect to time for two weeks. It can be observed that intensity magnitude was higher before the noon period in comparison to morning and evening period and maximum value of solar intensity reached up to 950W/m² and the magnitude of intensity was decreasing continuously after 12:00 AM.

(C) Variation of temperatures, collector efficiency and mass of the product

(a) With respect to time for sample 1 (chilly)

From the curves as in Figure 7, it was observed that collector temperature was higher than the drying chamber temperature and also from the ambient temperature for all the time during the day. Drying chamber temperature was approximately average of the collector and ambient temperature i.e. greater than ambient temperature and less than collector temperature.

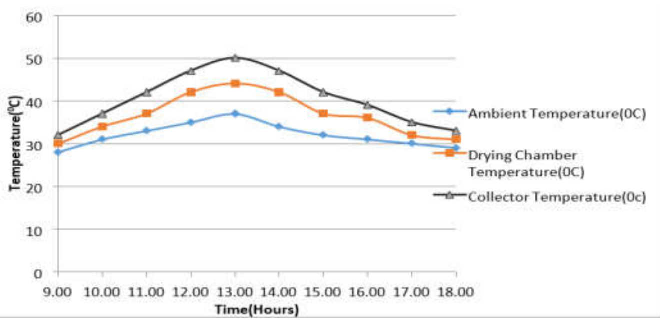

Figure 7 Variation of temperature versus time for sample 1 on day 1

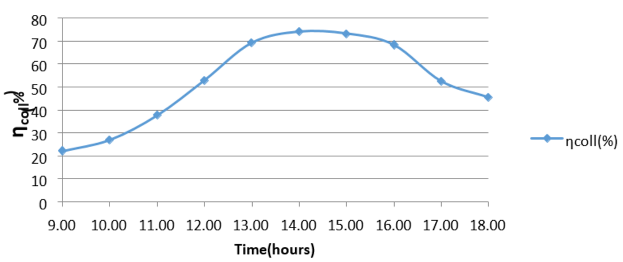

Figure 8 Collector efficiency versus time for sample 1 on day 1

It may be noticed in Figure 8 that collector efficiency was maximum and almost constant for the afternoon period because magnitude of intensity starts decreasing during the start of this period i.e. losses from the collector were minimum hence the efficiency of collector was maximum for the afternoon period.

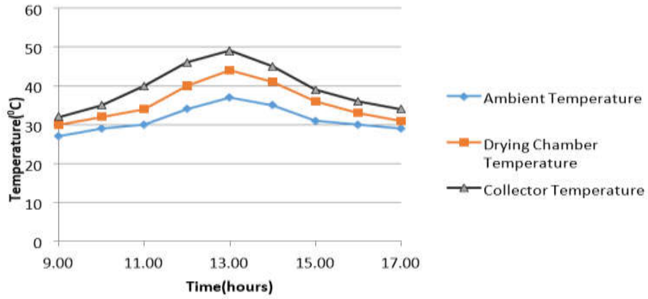

Figure 9 Variation of temperature versus time for sample 1 on day 2

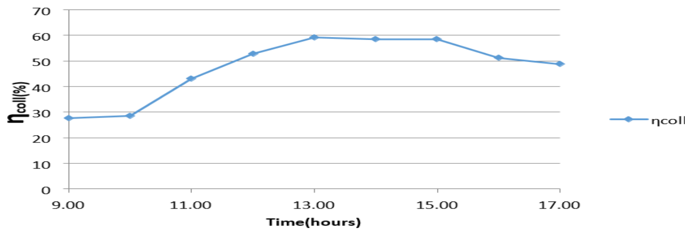

Figure 10 Collector efficiency versus time for sample 1 on day 2

Same as for the previous day, the temperature values were higher for the noon period, as seen in Figure 9. Maximum values of collector and ambient temperatures reach up to 49^{o} C and 37^{o} C respectively. Also the value of collector efficiency was higher for the afternoon period as observed in Figure 10.

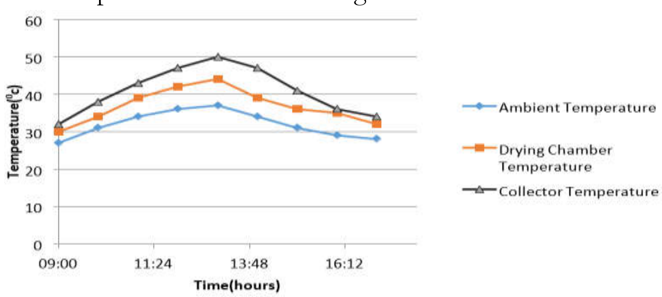

Figure 11 Variation of temperature versus time for sample 1 on day 3

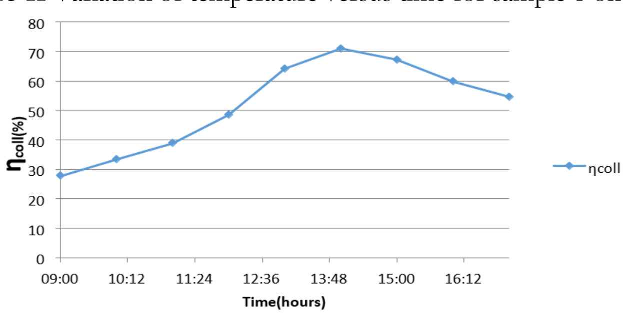

Figure 12 Collector efficiency versus time for sample 1 on day 3

Similar to the previous days, temperatures of all units as well as collector efficiency were higher for the afternoon period on day 3 as observed in Figure 11 and Figure 12.

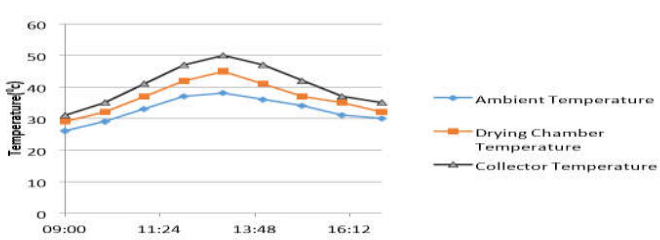

Figure 13 Variation of temperature versus time for sample 1 on day 4

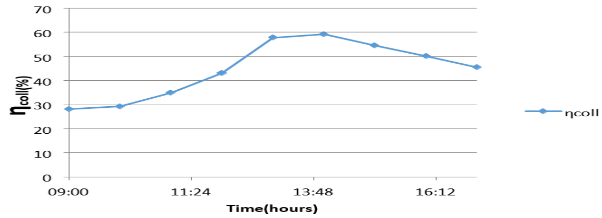

Figure 14 Collector efficiency versus time for sample 1 on day 4

Similar to the previous days the temperatures of all units were higher for the afternoon period as seen in Figure 13. At 01:00 PM collector temperature and also the temperature difference was highest. The collector efficiency was also maximum for the afternoon period because temperature difference was higher for the noon period as seen in Figure 14. Initially 500 grams of chilly have been placed in each of the tray for drying purpose and the dryer has been started then for every hour mass of every trays product was observed and also the moisture loss was calculated as shown in Table 1.

Table 1 Change in the mass of the product per hour for sample 1 during 4 days

Time of drying (hrs.)	Mass of chilly (grams)				Moisture loss	% moisture loss
	Tray 1	Tray 2	Tray 3	Total mass		
0	500	500	500	1500	0	0
2	482	489	495	1466	34	2.27
4	453	465	479	1397	103	6.87
6	434	448	458	1340	160	10.67
10	419	438	452	1309	191	12.73
12	373	398	408	1276	224	14.93
14	357	377	383	1117	383	25.53
16	329	352	367	1048	452	30.13
18	315	340	356	1011	489	32.60
20	292	323	338	953	547	36.47
22	278	309	320	907	593	39.53
24	268	291	306	865	635	42.33
26	257	276	285	818	682	45.47
28	240	252	262	754	746	49.73
30	235	237	239	711	789	52.60
32	234	235	235	704	796	53.07

It can be observed from Figure 15 that the mass of product in tray 1 was decreasing rapidly in comparison to tray 2, 3 because it was the lowest tray and the first one which comes into contact with the hot air coming from the collector. Thats why moisture removal rate from the tray 1 was highest and also rate of decrease of mass was higher. Figure 16 show total mass of product verus time which is observed to be contnously decresing with respect to time as expected from the data collected for a period of four days.

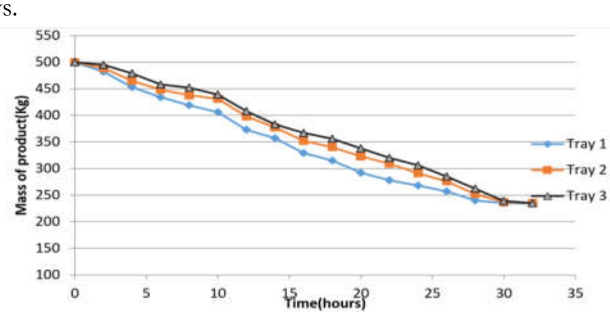

Figure 15 Mass of product in each tray versus time

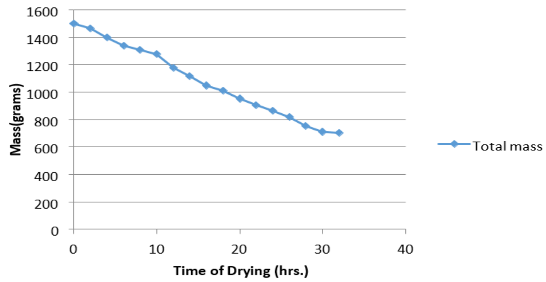

Figure 16 Total mass of product verus time

Figure 17 show the mass of water vapour removed per hour for the total period of drying. It can be seen in the plot that the removal of the moisture is highest for the noon period every day and in the end it is going towards zero.

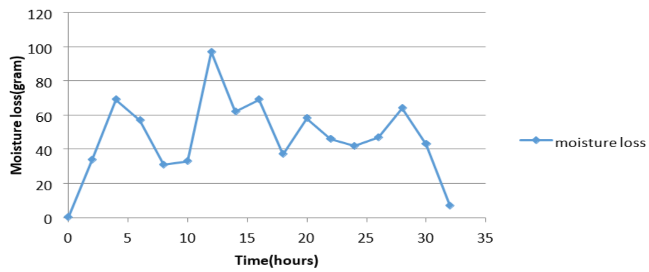

Figure 17 Moisture loss from the product versus time

(b) With respect to time for sample 2 (potato chips)

The trend of variation of temperatures as well as collector efficiency was similar to the previous data. It is observable from Figures 20-23 that the values of temperatures were higher for the noon period in comparison to morning and evening and also the collector efficiency was higher for afternoon period because collector efficiency also depends on the temperature difference of collector and ambient, which was maximum for afternoon period.

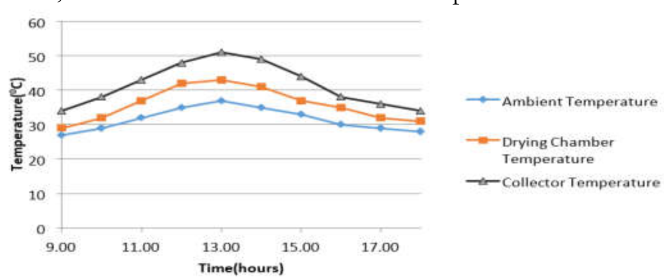

Figure 20 Variation of temperature versus time for sample 2 on day

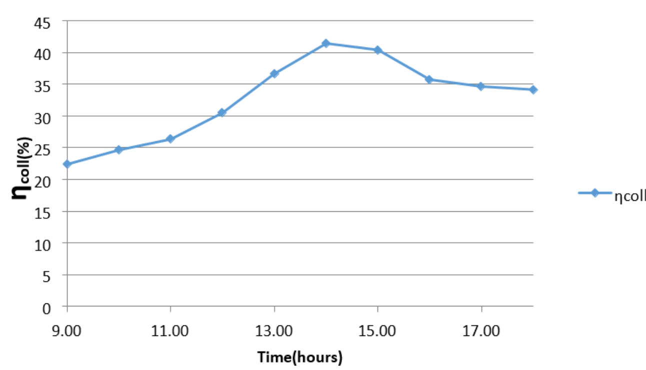

Figure 21 Collector efficiency versus time for sample 2 on day 1

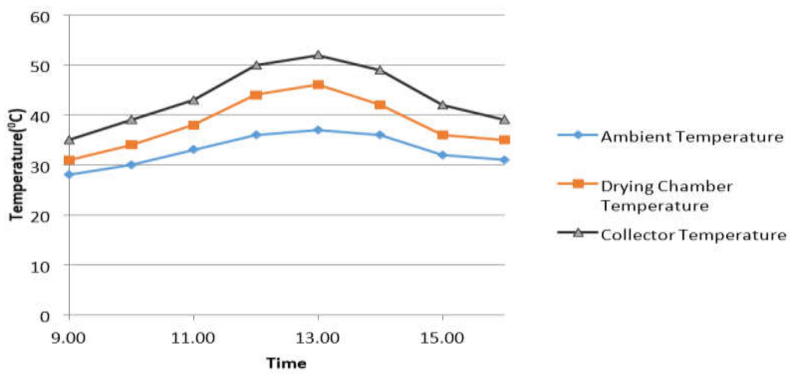

Figure 22 Variation of temperature versus time for sample 2 on day 2

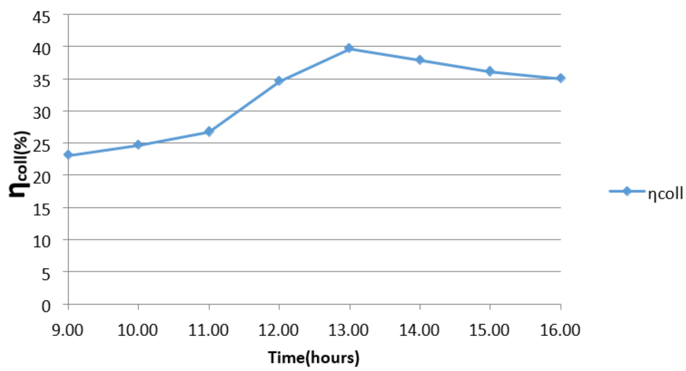

Figure 23 Collector efficiency versus time for sample 2 on day 2

Table 2 Change in the mass of the product for sample 2during 2 days

Time of drying (hrs.)	Mass of chilly (grams)				Moisture loss	% moisture loss
	Tray 1	Tray 2	Tray 3	Total mass		
0	500	500	500	1500	0	0
2	452	462	469	1386	114	7.6
4	346	366	382	1094	292	21.06
6	235	280	304	819	275	25.13
8	175	237	268	680	139	16.97
10	160	209	234	603	77	11.32
12	146	167	178	491	112	18.57
14	140	142	142	424	67	13.65

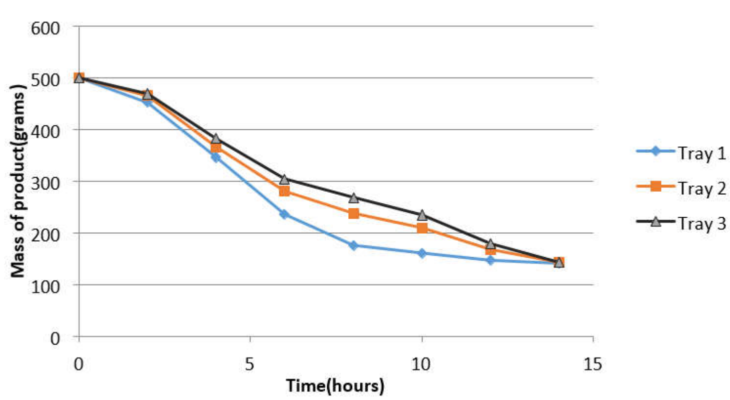

Figure 24 Mass of product in each tray versus time

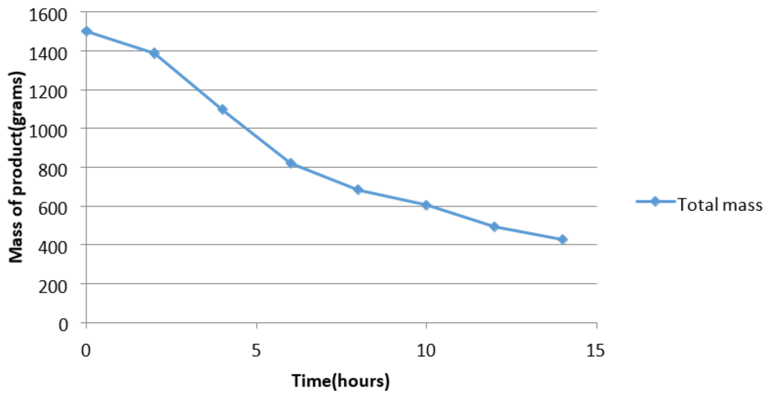

Figure 25 Total mass of product versus time

It can be noticed in Figures 24-25 that initially moisture removal rate was very high and the slope of mass versus time line is confirming this phenomenon. Initially slope of the line is higher because there was high amount of the water present in the product and it was coming out easily with respect to time. Going towards the end, it can be seen that slope of line is decreasing rapidly because of the presence of less amount of water in the product, for removing same amount of water it took more time in the last in comparison to beginning and the main reason of this was deficiency of the moisture in the product.

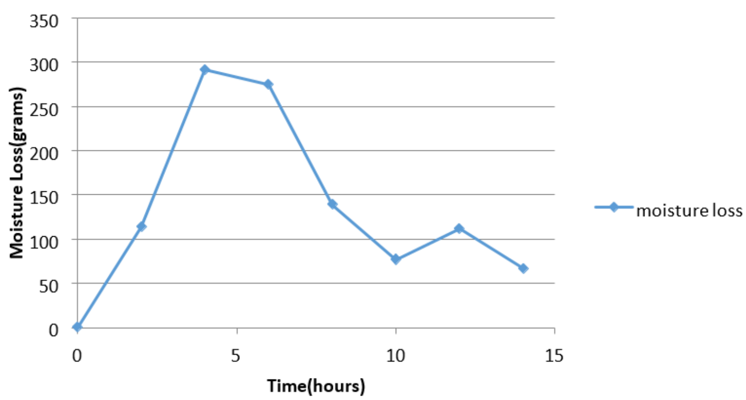

Figure 26 Moisture loss from the product versus time

From Figure 26 it is visible that the moisture removal rate was higher for the first day in comparison to the second day, as discussed for the previous sample it was happening because of less availability of the moisture content in the product at the last stage of drying thats why moisture loss per hour was less for the second day.

(D) Experimental efficiency

The collector efficiency depends on the temperature difference of the air through collector as well as intensity of radiation and overall efficiency depends on temperature difference, radiation intensity, mass of water vapour and drying time. The experimental efficiency should be less than that of theoretical efficiency because experiments have been done on the physical model which may not be perfect. The dimensions and profile may vary little bit and also the instruments which anyone uses may not be so much perfect. The experimental efficiency can be calculated by taking ratio of output energy and input energy as discussed below

Average collector efficiency for two weeks

$$\eta_c = \frac{Q_g}{A_c I_T}$$

η_c =42.3754%

Overall efficiency for sample 1

$$\eta_o = \frac{m_w \times L_v}{I_T A_c + P_f}$$

$$\eta_o = 26.0751\%$$

Overall efficiency for sample 2

$$\eta_o = 38.9761\%$$

From the above calculation, overall efficiency is higher for sample 2(potato chips) in comparison to sample 1(chilly) because transportation of moisture from inner body to outer surface of the product was simple and require less energy for removal process from the product for sample 2. This leads to less drying time requirement for removal of the same amount of moisture from the product for sample 2 and hence overall efficiency is higher for the sample 2.

VI. CONCLUDING REMARKS

From the tests carried out, following conclusions have been made. The solar dryer can raise the ambient air temperature to a considerable high value for increasing the drying rate of agricultural crops. The product inside the dryer requires less attentions, like attack of the product by rain or pest (both human and animals), compared with those in the open sun drying. Although the dryer was used to dry Potato, it can be used to dry other crops like maize, grains and banana etc. There is ease in monitoring when compared to the natural sun drying technique. The capital cost involved in the construction of a solar dryer is much lower to that of a mechanical dryer. A simple indirect mode solar dryer has been designed which is constructed using locally sourced materials. The hourly variation of the temperatures inside the collector and drying cabinet were much higher than the ambient temperature during the most hours of the daylight. The dryer exhibited sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product.

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