Development and Performance Analysis of Hybrid Type Solar Dryer Employing Solar Flat Plate Collector

The present paper represents the experimental investigation on performance testing of Hybrid type of solar dryer for drying food products in a hygienic way. The food products such as ginger, potato, tomato, bread were taken for drying and it was used during day as well as night purpose. The main components were solar flat plate collector ($1m^2$), drying chamber. The four numbers of DC blowers were used such as at inlet, outlet of collector and also at exhaust of drying chamber. The blowers were used for circulation of heated air inside the drying chamber as well as for exhaust purpose. The blowers were operated by solar panel, battery, and charge controller with a proper size. The components of flat plate collector were corrugated absorbing plate (3mm thickness of Aluminium sheet) and two numbers of transparent plates (tempered glass) were used for maximum transmittivity with a minimum gap of 3 cm in order to reduce the radiation losses from first glass plate. Further by using baffle in between the glass plate and absorbing plate, the convective heat losses was reduced as well as turbulence of the heated air inside the collector was increased which was main objective of this research. The parameters such as temperature, relative humidity, velocity of air at different point of dryer were measured by using different measuring instruments The Instantaneous efficiency of solar collector and overall loss coefficient were calculated as 48.73% and 2.11 $W/m^2 0_C$ by taking Bhubaneswar Latitude as (20.2961ºN, 85.8245ºE) .The maximum coefficient of performance was calculated as 0.789 by taking maximum outlet collector temperature and maximum drying chamber temperature. The heat removal factor and heat utilization factor were found as 0.8 and 0.22.The dryer was also used during night purpose by using a heated coil which was operated by inverter and battery.

Traditionally people dry the food products, vegetables and sea foods in an open and unhygienic condition which results poor prices realizations in the market. It also requires more times for drying .Also diesel or electricity operated dryer is mostly cost effective and not environmental friendly. So solar dryer is an alternative and effective method of drying food products in a hygienic way and quick process of drying.

Solar dryer systems are generally classified into two type's mainly direct type of solar dryer and indirect type of solar dryer. In direct type, the sun radiation directly expose on the drying chamber and food products gets dried by absorbing heated air circulated through it. But in Indirect type the sun radiation incident on collector and heated air which is generated inside it enters into the drying chamber. Again according to method of heating it is classified as 1. Active solar dryer or Hybrid type or Forced convection type solar dryer.2.Passive type or Natural convection solar dryer.

Nomenclature

1. m_w = Mass of water to be removed from fruits
2. m_i = Weight of fruits in kg
3. M_i= Initial moisture content in fruits
4. M_f = Final moisture content in fruits
5. $\dot{m}_a$ = Mass flow rate of dry air in kg/sec
6. C_p = Specific heat in kJ/kg-K
7. T_1 = Inlet temperature of collector
8. T_2 = Outlet temperature of collector
9. L = Latent heat of vaporization in kJ/kg-K
10. ρ_a = Density of air in kg/m^3
11. A_c = Collector area in m^2
12. H_o = Monthly average daily global radiation on horizontal surface kJ/m^2-day
13. H_d = Daily diffuse radiation on a horizontal surface in kJ/m^2-day
14. H_g =Daily global radiation on a horizontal surface in kJ/m^2-day

15. n = Number of days of the year
16. δ = declination angle in degree
17. ϕ = Latitude angle of Bhubaneswar.
18. w_s= Sunrise hour angle
19. S_{max} = Day length
20. E_L = Elevation from sea level
21. a_1 and b_1 = Constants
22. I_o = Monthly average of the hourly extra-terrestrial radiation on a horizontal surface (kJ/m^2-h)I_g = Monthly average of the hourly global radiation on a horizontal surface (kJ/m^2-h)
23. w= Hour angle
24. LAT = Local apparent time
25. I_d = Hourly diffuse radiation on a horizontal surface in kJ/m^2-h
26. θ = Zenith angle
27. r_b = Tilt factor for instantaneous/hourly beam radiation
28. r_d = Tilt factor for instantaneous/hourly diffuse radiation
29. I_t = Instantaneous/hourly flux incident of tilted surface.
30. Q_U= Rate of useful heat gain in Watt.
31. η= Instantaneous efficiency of solar collector
32. $(\tau\alpha)_e$= effective transmittance absorptance product
33. τ= Transmittance of glass plate
34. α= Absorptance of the absorbing plate
35. U_L= Overall loss coefficient in
36. T_p= Absorbing plate temperature in ^{0}C.
37. T_{sc}= maximum Solar collector temperature in ^{0}C
38. T_{rm} = maximum drying chamber temperature in ^{0}C
39. T_{am}= Atmospheric temperature in ^{0}C
40. F_R= Heat removal factor
41. d= diameter of DC blower at outlet of collector

Mathematical Modelling

m_i = 20 kg

M_i= 71%

M_f = 20%

$$m_w = \frac{m_i\left(M_i - M_f\right)}{\left(1 - M_f\right)} = \frac{20(0.71 - 0.2)}{1 - 0.2}$$ =12.75 kg of water to be removed from 20 kg of wet fruits

D.D Behera et.al [14]

$$\dot{m}_a C_p\left(T_2 - T_1\right) = m_w L$$

$$\dot{m}_a = \frac{m_w L}{C_p\left(T_2 - T_1\right)} = \frac{12.75 \times 2260}{1.005(72 - 45)}$$ =1061.912 kg of dry air

Assuming 24 hours to be dried

$$\frac{1061.912}{24 \times 3600} = 0.01229 \text{ Kg/sec of dry air}$$

Volume flow rate = $\frac{\dot{m}_a}{\rho_a} = \frac{0.01229}{1.225}$ = 0.01003 m^3/sec

Bhubaneswar latitude = 20.2961°N, 85.8245°E on 1st May

n = 31+28+31+30+31 = 151

$$\delta = \text{Declinatio n} = 23.45 \sin\left[\frac{360}{365}(284+151)\right] = 21.8984^o \qquad [14]$$

Ws = $\cos^{-1}(-\tan\phi\tan\delta)$ = $\cos^{-1}[-\tan(20.2961)\tan(21.8984)]$

= 98.5458 = sunshine

Hour angle = 1.719 radian

Day length S_{max} = $\frac{2}{15}(98.5458)$ = 13.139 hours

H_o = Monthly average daily global radiation

$$= \frac{24}{\pi} \times 1.367 \times 3600 \times \left(1 + 0.033\cos\left(\frac{360}{365}\right) \times 151\right)\{1.42 \times \sin 20.2961 \times \sin 21.8984 + \cos 20.2961 \times \cos 21.8984 \times \sin 98.5458\}$$

= 37595.198×5.982× (0.183+0.86) = 234694.72 kJ/m^2-day

By taking E_L = Elevation from sea level = 45 m = 0.045 km

Average sunshine hours per day => $\overline{S}$ = 11 hours

a_1= -0.309+0.539cosϕ -0.0693×E_L + 0.29 $\left(\frac{\overline{S}}{S_{max}}\right)$

= -0.309+0.539 cos (20.2961) - 0.0693×0.045 + 0.29 $\left(\frac{11}{13.139}\right)$

= 0.436

b_1 = 1.527-1.027 cosϕ +0.0926 E_L - 0.359 $\left(\frac{\overline{S}}{S_{max}}\right)$

= 1.527-1.027 cos (20.2961) + 0.0926 × 0.045 - 0.359 $\left(\frac{11}{13.139}\right)$

= 0.267

$$\frac{\overline{H}_g}{H_o} = a_1 + b_1\left(\frac{\overline{S}}{S_{max}}\right) = 0.436 + 0.267\left(\frac{11}{13.139}\right)$$

= 0.659

$\overline{H}_g$ = 154862.63 kJ/m^2-day

$$\frac{\overline{H}_d}{H_g} = 1.411 - 1.696\left(\frac{\overline{H}_g}{H_o}\right) = 1.411 - 1.696\left(\frac{154862.63}{234694.72}\right)$$

= 0.292

$\overline{H}_d$ = 0.292 × 154862.63 = 45219.88 kJ/m^2-day

Hour angle, w = 12 hours – 4 (standard time longitude – longitude of location)
= 12 hours – 4 (82.5 – 85.82)
= 12 hours – 10.78 minutes
= 11.49 minutes

w = $11.49 \times \frac{15}{60} 2.8725^o$

a = 0.409 + 0.5016 sin (w_s - 60)
= 0.409 + 0.5016 sin (98.5458 - 60)
= 0.721

b = 0.6609 - 0.4767 sin (w_s - 60)
= 0.6609 - 0.4767 sin (98.5458 - 60)
= 0.3639

$$F_c = a + 0.5 b \left[\frac{\frac{\pi w_s}{180} - \sin(w_s)\cos(w_s)}{\sin(w_s) - \frac{\pi w_s}{180}\cos(w_s)} \right]$$

$$= 0.721 + 0.5 \times 0.3639 b \left[\frac{\pi \times 1.719 - \sin(98.5458)\cos(98.5458)}{\sin(98.5458) - \frac{\pi \times 1.719}{180}\cos(98.5458)} \right]$$

$$= 0.902 \left[\frac{5.549}{0.988 - \left(-4.458 \times 10^{-3}\right)} \right]$$

= 0.895

$$I_o = 1.367 \left[1 + 0.33 \times \cos\left(\frac{360}{365}\right) \times n \right] \times \left[\sin\phi \sin\delta + \cos\phi \cos\delta \cos w\right]$$

$$= 1.367 \left[1 + 0.33 \times \cos\left(\frac{360}{365}\right) \times 151 \right] \times \left[\sin 20.2961 \sin 21.8984 + \cos 20.2961 \cos 21.8984 \cos 2.8785\right]$$

= 532.765 kJ/m^2-h

$$\frac{I_g}{H_g} = \frac{I_o}{H_o}(a + b\cos w)/F_c$$

I_g = $154862.63 \times \frac{532.765}{23469.72} \times (0.721 + 0.3639 \times \cos 2.8985)/0.895$

= 425.59 kJ/m^2-h

$$\frac{I_d}{H_d} = \frac{I_o}{H_o}$$

$$I_d = \frac{532.7650}{234694.72} \times 45219.88$$

I_d = 102.65 kJ/m^2-h

Zenith angle = cos θ = $\sin\phi \sin\gamma + \cos\phi \cos\gamma \cos w$

$$= \sin(20.2961)\sin(0) + \cos(20.2961)\cos(0)\cos(2.8725)$$

θ = 20.495°

$$r_b = \frac{0.936}{\sin\phi\sin\delta + \cos\phi\cos\delta\cos w}$$

= 0.9378

$$r_d = \frac{1+\cos\phi}{2} = \frac{1+\cos(20.296)}{2} = 0.9689$$

$$r_r = \frac{0.2(1-\cos\phi)}{2} = \frac{0.2(1-\cos(20.296))}{2}$$

= 6.20 ×10^{-3}

$$\frac{I_T}{I_g} = \left(1 - \frac{I_d}{I_g}\right) r_b + \frac{I_d}{I_g} r_d + r_r = \left(1 - \frac{102.65}{425.59}\right)0.9378 + \frac{102.65}{425.59}0.9689 + 6.20\times10^{-3}$$

I_T = 404.94 W/m^2

Assuming 50% instantaneous efficiency

$$\eta = \frac{\dot{m}_a C_p (T_2 - T_1)}{A_c \times I_T}$$

$$0.5 = \frac{0.01229\times1005(72-45)}{A_c \times 404.94}$$

$$0.5 = \frac{0.01229\times1005(72-45)}{A_c \times 404.94}$$

$$A_c = 1.647\,m^2$$

$$A_c = L \times B = 1.28 \times 1.28$$

2. Material and Methods

2.1 Components of Hybrid types of Solar Dryer

The main components of Hybrid types of solar dryer are solar flat plate collector, Drying Chamber, Solar Panel, Charge controller, battery, DC blower, Inverter, Electric Coil

2.1.1 Solar flat plate collector

(a). The main component of Flat plate collector was transparent cover plate, absorbing plate, glass wool. The area of collector was taken as 1m^2.The main function of transparent cover is to transmit as much as solar radiation to absorbing plate and also minimize the heat loss due to re radiation from the absorbing plate. The two numbers of transparent cover plates were taken as tempered glass having 5 mm thickness and gap of 3mm was given in between two glass plate in order to increase transimitivity.

(b).The main function of absorbing plate is to absorb the incident sun radiation which was transmitted by glass plate. The Aluminium sheet was preferred as absorber as it has good corrosion resistance and also having good thermal conductivity. The 3mm thickness of black coated Aluminium sheet was taken and it was made corrugated to increase the heat transfer rate. Inside the collector a baffle was provided in order to increase turbulence effect of heated air inside the collector. The glass wool of 10 mm was provided in order to increase the back loss of heated air from the collector.

2.1.2 Solar drying chamber

The drying chamber was made up of stainless steel having size Length×bradth×height (1m×50cm×50cm).The 3 no of stainless steel wire mesh type treys were inserted inside the drying chamber with evenly spaced.

2.1.3 Electrical connection

(a) The Solar Panel with sizing (Maximum power=20 Watt, Maximum voltage=17 volt, Maximum current=1.18 Ampere), battery sizing (12 Volt, 20 Ampere hour), Charge controller (12 Volt, 10 amp) were connected electrically to run the DC blower.

(b). 4 no of DC blowers with sizing (6 volt, 0.6 amp) were connected such as at inlet of collector, at outlet of collector and at outlet of drying chamber. Out of 4 numbers two were connect in series and one were connected in parallel to satisfy the maximum voltage and current in the circuit. The DC blowers were provided for even distribution of heated air inside the drying chamber and also exhausting the moist air from the drying chamber. The inverter (100 Watt), coil (50 watt, 5 ampere) was used for drying during night time and it was operated by battery.

2.2. Experimental Set up

The figure 1 and 2 shows the experimental set up of Hybrid type of solar dryer. The sizing of the collector and drying chamber were carried out by considering various parameters such as atmospheric temperature, relative humidity and the amount of food products to be dried. The collector was tilted as per the latitude of Bhubaneswar location (20.2961ºN, 85.8245ºE).So the Collector was tilted with 20^0 and facing due south so that more amount of sun radiation incident on the collector. There was proper circulation of heated air inside the drying chamber due to the presence of two numbers of dc blowers at outlet of collector. The test was conducted in the month of February by taking food products such as Potato, tomato, ginger, bread. The two numbers of glass plates were provided to enhance the transmittance power as well to reduce the losses due to re radiation. The baffle was provided to reduce the convective heat losses as well as to increase the turbulence effect of heated air inside the collector. The dryer was used during the night purpose by using heated coil which was run by inverter and battery.

Table 1. Shows specification of different component of Hybrid type of solar dryer.

Sl.No	Parameter	Specifications
1.	Solar Collector Type	Flat plate air- heating solar collector
2.	Loading	Opening doors at back side
3.	Number of Trays	3
4.	Number of Doors	2
5.	Air Circulation	Forced
6.	Drying Capacity	20 kg-Fresh
7.	Construction Materials	Stainless steel wiremesh, aluminium sheets, (absorbing plate), window glass, glass wool.
8.	Flat Plate Air- Heating Solar Collector is of size	1000mm x 1000mm
9.	Solar Dryer Box size (Lx B x H)	1000mm x 500mm x 500mm
10.	Diameter of fan(dc blower)	60 mm
11.	Solar pannel	Pmax=20W, Vmax=17V, Imax=1.18A, Voc=21.50V, Isc=1.29 Amp

12.	Charge controller (CCR)	12 V, 6 Amp
13.	Inverter	100 watt, 1GBT model
14.	Blower	12 V, 0.6 Amp
15.	Battery	12 V, 20 Ah
16.	Coil	50 W, 5 Amp

Figure 1. Experimental set up of front side of Hybrid type of Solar dryer.

1. DC blower at inlet of collector, 2. Absorbing plate, 3. Baffle 4. Drying Chamber, 5. Solar Panel

Figure 2. Experimental set up of back side of Hybrid type of Solar dryer. Figure 3. Experimental set up for night purpose

The following are the main components of Figure 2.

1. Battery, 2. Stainless steel wire mesh trey, 3and 4.Two numbers of blowers at outlet of collector, 5. Charge controller 6.exhaust fan at outlet of drying chamber.

The following are the main components of Figure 3.

1. Inverter 2. Heated coil.3. Glass wool

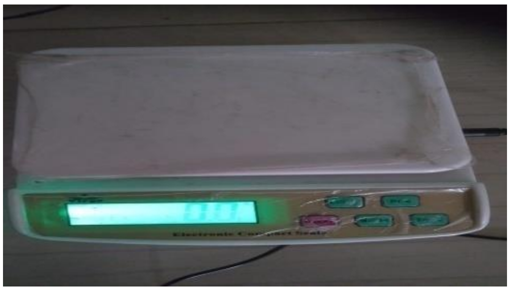
3. Result Analysis and Discussion:

To do the performance testing of Hybrid type of Solar Dryer, the dryer was taken in an open shadow free location where the maximum sun radiation was incident on the surface. It was facing due south and was tilted according to the latitude of that location. The various parameters like temperature, Absolute humidity, wind velocity, velocity of blowers at various point of dryer such as at inlet of the collector, on glass plate outlet of the collector, in the drying chamber and at outlet of drying chamber at a regular interval of time. It was tested throughout the day in a sunny day to dry the ginger, bread, potato, tomato. The Infrared Thermometer, hygrometer, Anemometer, weight measuring machine were taken to measure the temperature, Absolute humidity, atmospheric wind velocity, velocity of blowers and percentage of weight reduction.

(Anemometer)

(Hygrometer)

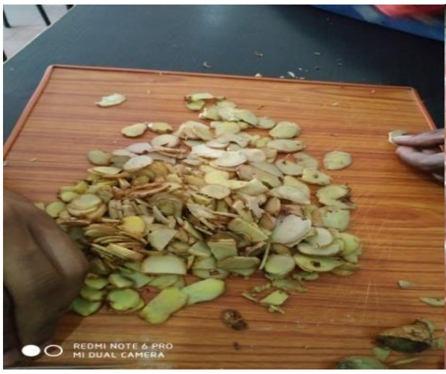
(Infrared Thermometer**)**



(Weight Machine)

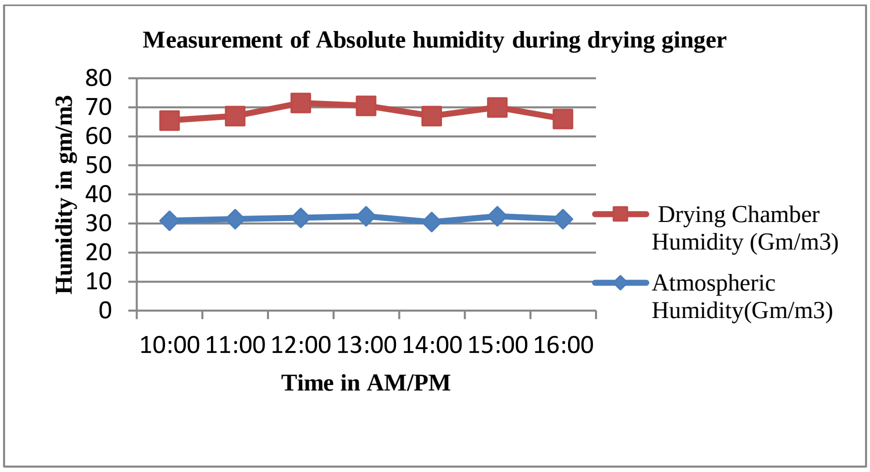
(Figures showing various types of measuring instruments during testing and analysis)

The experiment started first day to measure various parameter like relative humidity, temperature, wind velocity and diameter of ginger. The relative humidity, temperature and wind velocity obtained from the experiment are shown in table below.

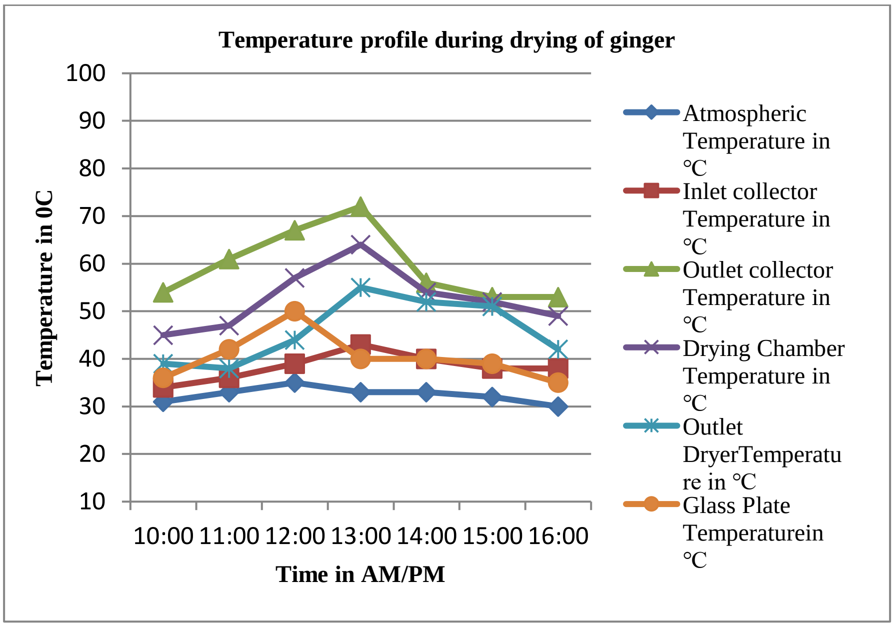


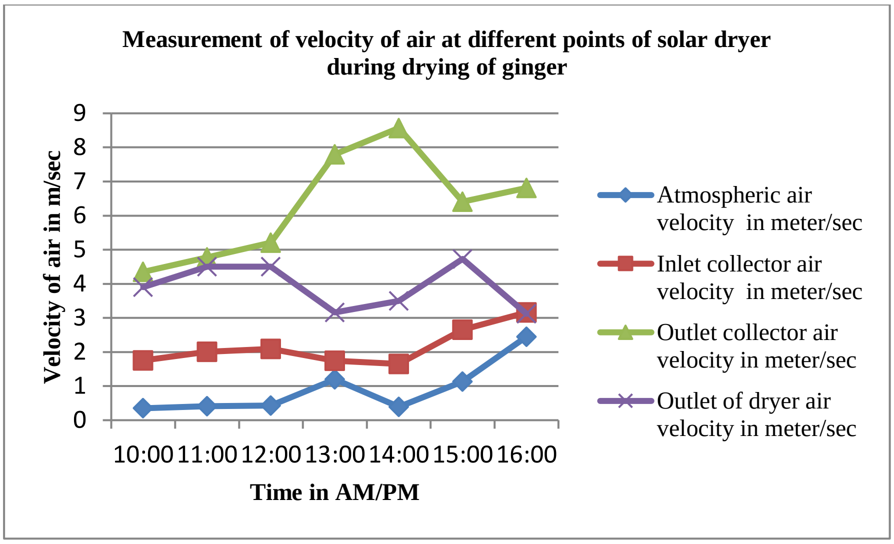
(Figure 1.showing drying of ginger in 1st day of observation)

Graph 1: Absolute humidity vs. Time



Graph 2: Measurement of temperature during drying ginger





Graph 3: Measurement of velocity of air of solar dryer for drying ginger

Initial weight of ginger= 233 gm

Final weight of ginger= 55gm

Determination of Moisture content on weight basis

$=\frac{initial\ weight-final\ weight}{initial\ weight}\times 100=\frac{233-55}{233}\times 100=76.39$gm/m³

Time required for drying potato=5 hours

Rate of reduction of ginger= $\frac{initial\ weight-final\ weight}{time\ taken}=\frac{233-55}{5}=$ 35.6%

The experiment started 3rdday to measure various parameters like relative humidity, temperature, wind velocity and diameter of potato. The relative humidity, temperature and wind velocity obtained from the experiment are shown in table below.

(Figure 2.showing drying of potato in 2nd day of observation)

Initial weight of potato= 300 gm

Final weight of potato= 69.5 gm

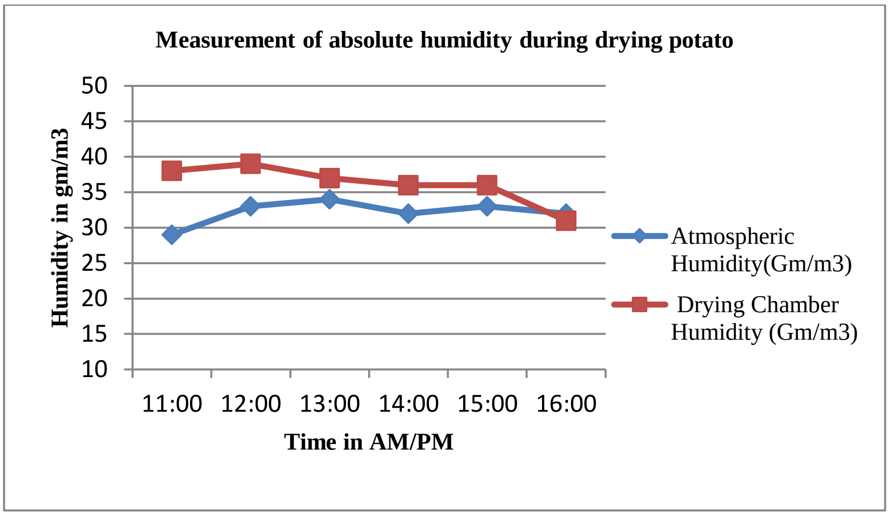
Determination of Moisture content on weight basis

$=\frac{initial\ weight-final\ weight}{initial\ weight}\times 100=\frac{300-69.5}{300}\times 100=76.83$ gm/m³

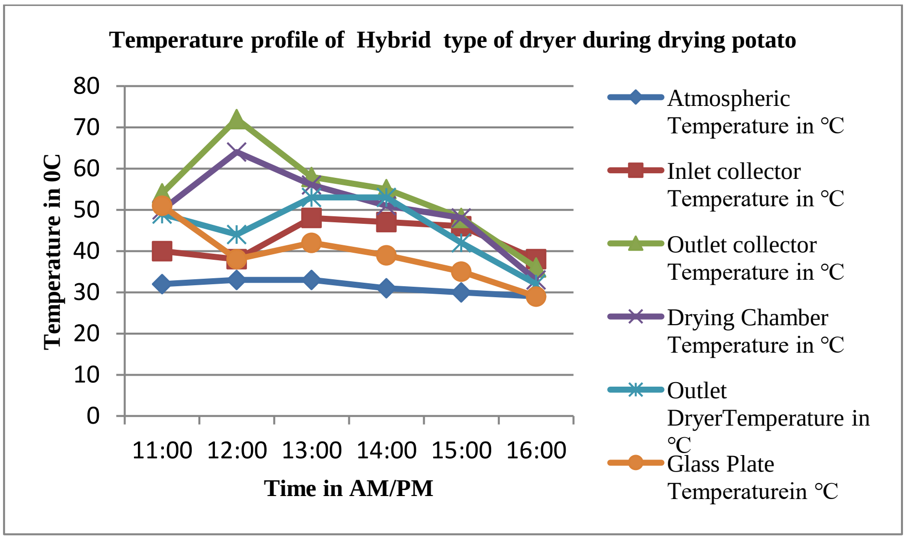
Rate of weight reduction of potato or drying rate

Time required for drying potato=5 hours

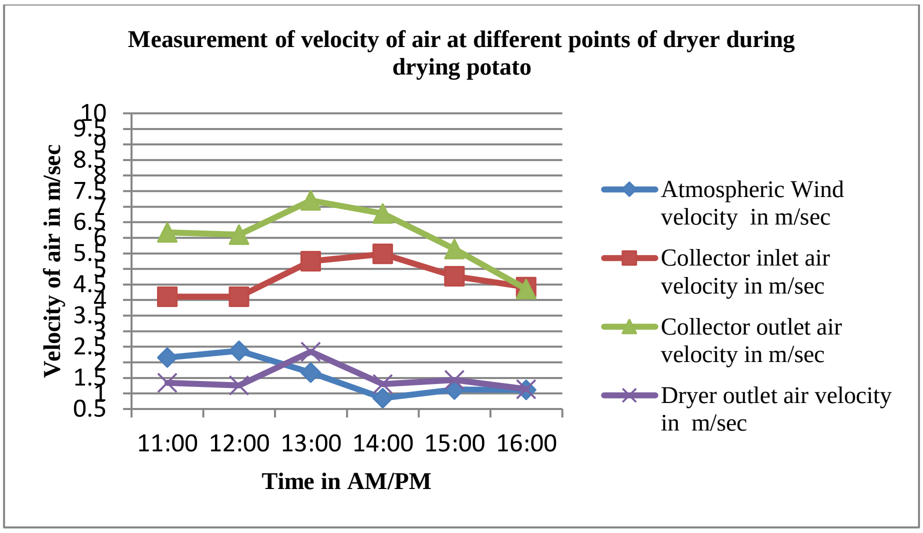
$= \frac{initial\ weight - final\ weight}{time\ taken} = \frac{300-69.5}{5} = 46.1\%$



Graph 4: Absolute humidity vs. Time during drying potato



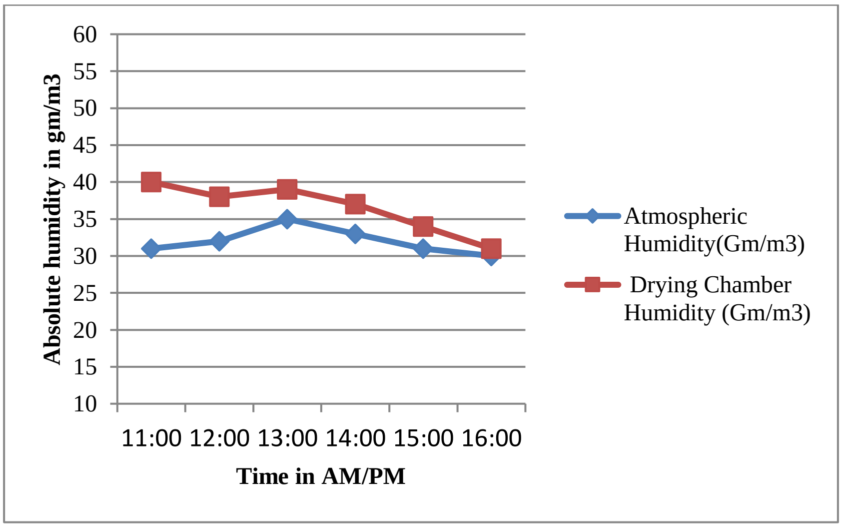
Graph 5: Measurement of temperature during drying potato



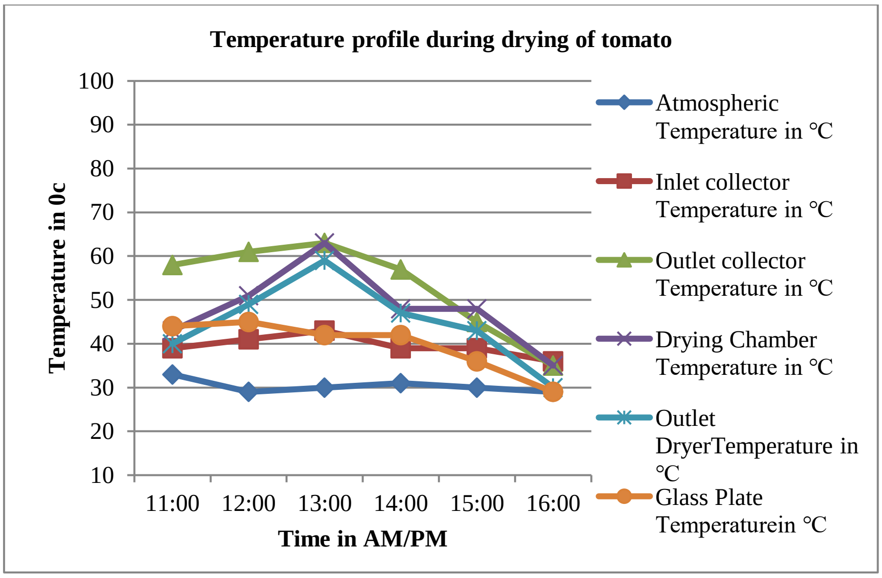
Graph 6: Measurement of velocity of solar dryer for drying potato at various points

The experiment started 4th day to measure various parameter like relative humidity, temperature, wind velocity and diameter of tomato. The relative humidity, temperature and wind velocity obtained from the experiment are shown in table below.

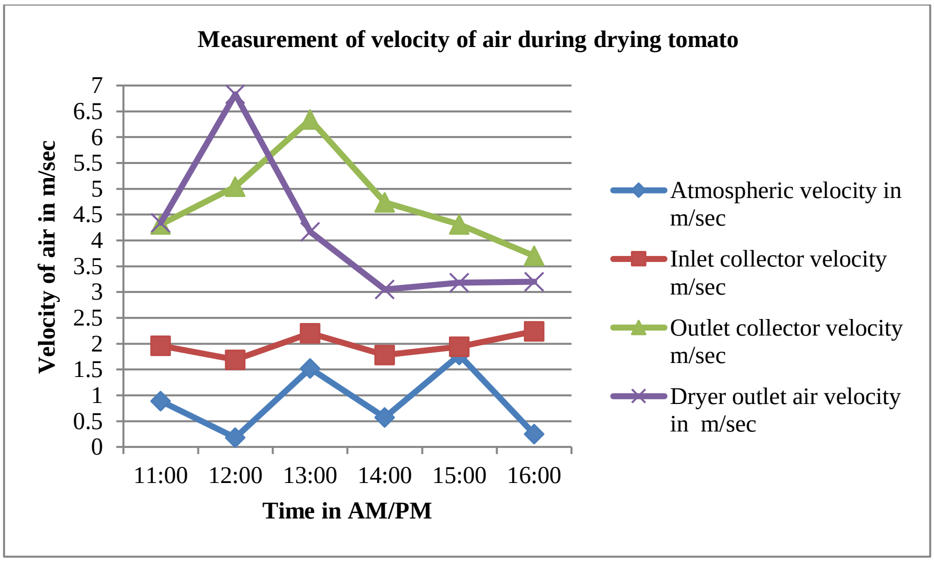
(Figure 3.showing drying of tomato in 3rd day of observation)



Graph 7: Absolute humidity vs. Time during drying tomato



Graph 8: Measurement of temperature during drying tomato



Graph 9: Measurement of velocity of solar dryer for drying tomato at various points

Initial weight of tomato= 620.3 gm

Final weight of tomato= 44.8gm

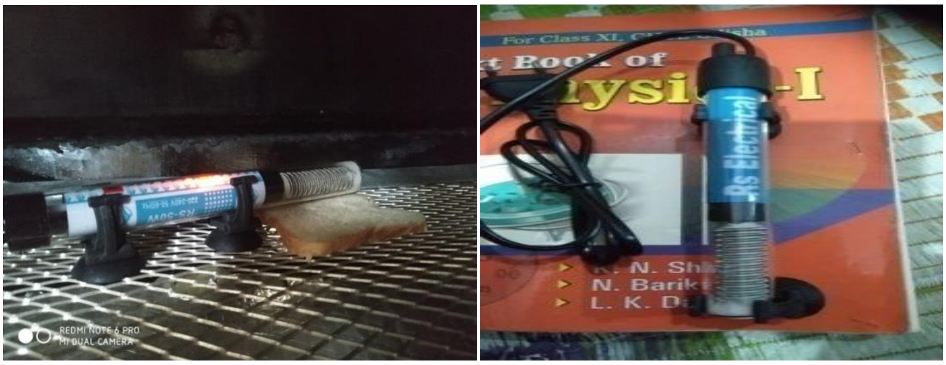
Determination of Moisture content on weight basis

$= \frac{initial\ weight - final\ weight}{initial\ weight} \times 100 = \frac{620.3-44.8}{620.3} \times 100 = 92.77$gm/m³

Time required for drying potato=6 hours

Rate of weight reduction of tomato or drying rate = $\frac{initial\ weight - final\ weight}{time\ taken} = \frac{620.3-44.8}{6}$ = 95.8%

This experiment has been conducted to measure temperature at night. The experiment started to measure temperature of bread. Parameter temperature is observed hour to hour interval.



(Figure 4.showing drying of bread during night period)

Sl no	Time(PM)	Drying Chamber Temperature in℃
1	05:30	45
2	05:45	50
3	06:15	56
4	06:03	61
5	06:45	65
6	7	69

Table 1.showing drying of bread during night period (Time verses Drying chamber temperature in 0_C)

Initial weight of bread= 200 gm

Final weight of bread= 150gm

Moisture content on weight basis = $\frac{initialweight-finalweight}{initialweight} \times 100 = \frac{200-150}{200} \times 100$ =25gm/m³

Time required for drying potato=0.6 hour

Rate of weight reduction of bread or drying rate =$\frac{initialweight-finalweight}{timetaken} = \frac{200-150}{0.6}$= 83.33%

3.1 Performance analysis of Hybrid solar Dryer

3.1.1 Calculation of Instantaneous Efficiency= $\eta = \frac{\dot{m}_a C_p (T_2 - T_1)}{A_c \times I_T}$

$\dot{m}_a = \rho_a \times A \times V_{air} = \rho_a \times \pi/4 \times d^2 \times V_{air}$

By taking diameter of DC blower as 60 mm and maximum velocity of heated air (V_{air})= 1.74 m/sec

η= Instantaneous efficiency of solar collector

=1.024× π/4×0.06×0.06×1.74× (72-33) ×1005/ (404.94×1) =48.73%

By taking maximum velocity of air at outlet of collector V_{air}==1.74m/sec, $\rho_{a=}$1.024 kg/m^3, d=diameter of blower,

A_c= Area of Collector in m^2 and I_T= 404.94 W/m^2

$Q_{u=}$Useful heat gained=$\dot{m}_a \times C_p \times (T_2-T_1)$ =197.356 W

$Q_u = A_c [I_T (\tau\alpha)_e - U_L (T_P - Ta)]$ [15]

$(\tau\alpha)_e = \tau.\alpha/1-(1-\alpha)\rho_d = 0.88\times0.22/1-(1-0.9)\times0.24 = 0.176/0.228 = 0.811$

$197.356 = 1[404.94\times0.811 - U_L (95-33)$

$U_L = 2.11 W/m^2 0_C$

$Q_u/ A_c = F_R [I_T(\tau\alpha)_e - U_L(T_2 - T1)] = F_R[404.94\times0.811 - 2.11(72-33)]$

$F_R = 0.8$

Heat utilization factor=$[T_{sc}-T_{rm}/T_{sc}-T_{am}]$=[72-64/72-33]=0.22

Coefficient of performance (COP) = $[T_{rm}-T_{am}/ T_{sc}-T_{am}]$ =64-33/72-33=0.7948

Percentage of heat with respect to ambient air temperature= $Q_{hg}=T_{rm}-T_{am}/ T_{rm}\times100$=72-33/72×100=1-33/72=0.55

4. Discussion

1. The figure 1 shows the drying of ginger for making ginger powder in a sunny day (on 18th February, 2019). It was taken 6 hours for drying the ginger. The initial and final weight of ginger was measured to calculate the percentage of weight reduction.
2. The graph 1 represents the comparison between absolute humidity of atmospheric air and heated air which circulates inside the drying chamber. It was observed that humidity inside the drying chamber is more as compare to atmospheric air because it absorbs moisture content from the food products to be dried.
3. The graph 2 shows the temperature of Hybrid type of solar dyer at various points like atmospheric temperature, at inlet of collector, glass plate outlet of collector, drying chamber, at outlet of drying chamber verses time period by using Infrared Thermometer. The maximum temperature at outlet of collector was found to be 72^0C where atmospheric temperature was 33^0C.It was found from the graph that the temperature gradually increases at various point of dryer from 10 AM to 1 PM after that the temperature gradually decreased. The maximum temperature was reached 64^0C inside the drying chamber and at outlet of dryer was found to be 55^0C.From the temperature profile it has been seen that, there was loss of heat at outlet of solar dryer, the heated air again recirculated to the inlet of collector.
4. Four numbers of DC blowers were connected at inlet of collector, outlet of collector and at outlet of drying chamber for even distribution of heated air inside the drying chamber and also for exhausting the moist air from the drying chamber. From the graph 3 it was observed that there was slight difference of velocity air of the blower which was measured by Anemometer. Hence a constant mass flow rate of air was maintained as it was integrated with solar Photovoltaic Panel, charge controller and battery.
5. The graph 4 represents the comparison between absolute humidity of atmospheric air and heated air which circulates inside the drying chamber while drying the potato.
6. The graph 5 represents the temperature profile of solar dryer at various points during drying the Potato for making potato chips. The maximum temperature was measured 55.8^0C while at outlet of collector while inside the drying chamber it was 51.5^0C.The time taken for drying the potato was found to be 3 days.
7. The graph 6 represents the rate of velocity of air for blower at inlet of collector, outlet of collector and at outlet of drying chamber during drying potato. There was very little difference of mass flow rate of air as it was integrated solar Photovoltaic system.
8. The graph 7 represents the comparison between absolute humidity of atmospheric air and heated air which circulates inside the drying chamber while drying the tomato.
9. The graph 8 represents the temperature profile of solar dryer at various points while drying tomato. The maximum temperature was found 63.3^0C on first day while inside the drying chamber it was 62.8^0C which was sufficient enough for drying tomato within 3 days.

10. The graph 9 represents the rate of velocity of air for blower at inlet of collector, outlet of collector and at outlet of drying chamber while drying the tomato. There was very little difference of mass flow rate of air as it was integrated solar Photovoltaic system.
11. The table 1 represents the testing of solar dryer during the night time. The temperature reading was taken from 5.30 PM to 7 PM for drying breads by using heated coil (50 watt, 5 Amp) which was operated by 100 watt inverter.

5. Conclusion

The main objective of this paper is to develop and to do performance testing of Hybrid type of solar dryer for using in day time as well as at night time. The dryer was utilized to dry the various food products such as tomato, potato, ginger and bread and also the temperature, relative humidity and velocity of air at various points of solar dryer were measured for doing performance test. Following conclusion were made by experiment

1. The maximum temperature reached with 72^0C at outlet of solar collector where as 64^0C inside the drying chamber.So there were some heat losses from the collector to drying chamber and over all heat loss was calculated as $2.11W/m^2 0_C$.Further it was observed that at exhaust of drying chamber the temperature lost by 55^0C for which it was again recirculated inside the collector by connecting a pipe from exhaust of drying chamber to the inlet of collector. The maximum absorbing plate was found as 95^0C.
2. By using two numbers of transparent glass plates, the radiation heat losses were reduced. But there was very small difference of temperature in between the two transparent glass plates. There was a very small difference in temperature for three numbers of wire meshed plates inserted inside the drying chamber as DC blowers were used at outlet of collector for even distribution of heated air inside the drying chamber.
3. The coefficient of performance was calculated 0.7948 where as Percentage of heat with respect to ambient air temperature was calculated as 0.55.