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Performance evolution of natural convection type solar tunnel dryer for drying indian gooseberry (amla)" Amla fruit

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ABSTRACT

The sun is the source of all energy that provides us heat and light energy free of cost. It is one of the major Renewable energy source. Therefore to preserve food products for longer period of time this energy can be used most efficiently. And it has been established as the most efficient preservation technique for most tropical crops. The traditional method of drying, known as 'sun drying', involves simply laying the product in the sun on mats, roofs or drying floors. Major disadvantage of this method is contamination of the products by dust, birds and insects and the method totally depends on good weather conditions. To reduce this disadvantage, we use different methods and one of the most common method is natural convection type solar tunnel dryer. In this paper presentation "Performance evolution of natural convection type solar tunnel dryer for drying indian *gooseberry (amla)" Amla fruit which is rich in vitamin C and tannins has an important value in Ayurvedic system of medicine. A walk in type Semi cylindrical solar tunnel dryer for drying 150-200kg Amla per batch has been commissioned at Department of Mechanical Engineering, UCE (RTU), Kota, Rajasthan, India. A solar tunnel dryer with 27.59m2 solar collector area was sufficient for drying Amla from 79% to 9.96% moisture content wet basis in 14–15hour, to indicate the performance of solar tunnel dryer. The results are shown in terms of the variation of air temperature, solar flux density, relative humidity, air flow rate, moisture content, etc., which were found quite encouraging. The results are also compared with natural sun drying method.*

I.INTRODUCTION ABOUT SOLAR ENERGY

One of the major renewable energy sources is the solar energy which sun emits to the earth. The sun is the central energy producer of our solar system. The solar radiation intensity outside the atmosphere is in average 1,360W/m^2 (solar constant). When the solar radiation penetrates through the atmosphere some of the radiation is lost so that on clear sky sunny day in summer between 800 to 1000W/m^2 (Global Radiation) can be obtained on the ground [17].

Concept of solar drying

Drying is a heat and mass transfer process resulting in the removal of moisture, by evaporation from a product presents in solid, semi solid state. The drying technique is probably the oldest and the most important method of food preservation practiced by human being.

Introduction about solar tunnel dryer

The solar tunnel dryer can be an efficient system for drying agricultural and industrial products for reducing the drying time and cost of drying operations. [1]

A solar tunnel dryer is essentially a poly house having tunnel like framed structure covered with ultra-violet (UV)-stabilized polythene sheet having height 2.25meter. The orientation of tunnel solar dryer is in east-west direction.

Objectives of paper

On the basis of Essential Scope of tunnel dryer, two objectives are formulated:

- Performance evolution of natural convection type solar tunnel dryer for drying *indian* gooseberry (amla)" Amla fruit in relation to weather parameters such as ambient air temperature, relative humidity, wind velocity and solar insulation and evaluate performance in term of weather conditions.
- The results are also compared with natural sun drying method.

System description of natural convection solar tunnel dryer at UCE, RTU, Kota

- Figure shows a front view of a natural convection solar tunnel drying system, designed and developed for drying agricultural and ayurvedic products Amla (Indian Gooseberry) on large scale at moderate temperature in this region. A solar tunnel dryer has been commissioned at Department of Mechanical Engineering, UCE, RTU, Kota at (25^0 14'N, 75^0 80'E) Rajasthan, India for drying 150-200kg Amla from 80-82% to 9-10% moisture content (dry basis) of in a batch. It is consisted of a hemi-cylindrical walk-in type metallic frame structure covered with UV-stabilized semitransparent polyethylene sheet of 200 micron thickness and had a base area of $3.75 \times 5m^2$ for drying 150-200kg per batch. The orientation of solar tunnel dryer is in east west direction [1].
- The product to be dried is put into a continuous perforated tray in thin layers. Two chimneys were placed on equidistance apart on the top of tunnel to remove moisture during drying. On the bottom side of southern side, three holes having equal diameter as that of chimney were provided to allow fresh air entry into tunnel. This fresh air gets heated and owing to density difference moves upward through the products and picked up moisture and finally passed out through chimneys.

Figure1.2: Front view of solar tunnel dryer at UCE, RTU, Kota

- Dimension of solar tunnel dryer at RTU, Kota.

Table 3.1: Components of solar tunnel dryer with their Specifications.

Sr. No.	Components	Specifications
1.	Length of tunnel dryer	*5.12 m*
2.	Diameter of tunnel dryer	3.75 m
3.	Floor area of solar tunnel dryer	19.21 m^2
4.	Area of semi cylindrical shape of solar tunnel dryer	41.07 m^2
5.	Length of north wall	5.12 m
6.	Tray size/bad size	1.3×2.3 m^2
7.	No. of chimney	2

II.EXPERIMENTAL SETUP

The performance of the drier was evaluated by conducting tests at no-load and loading with Amla pulp, measuring the following parameters:

a) Radiation incident on the Collector/dryer,

b) Air temperatures at various locations in the dryer,

c) Air velocity

d) Relative humidity by data logger

e) Radiant flux density

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f) Moisture content variations

To measure the temperature of air at various locations of the tunnel dryer, K-type Thermocouples were installed at various points along the length and breadth of the solar tunnel dryer, three thermo sensors inside and one thermo sensor outside the solar tunnel dryer kept for recording. Sensors number first, second, third and forth were kept inside the solar tunnel at mid bottom point, at 1m above mid bottom point, at north wall and at the inlet of chimney respectively and sensor number five was kept outside the solar tunnel dryer. All temperature data was registered at an interval of one hour by a data logger. Drying tests were started at 9:00 hours and stopped at 17:00 hours in the month of December. The daily drying rate was estimated by measuring the weight loss of the product after each day of drying. The sun dried control samples were weighed for comparison. The initial and final moisture contents of the product before and after each day of drying were ascertained by the oven method. The relative humidity of air inside the dryer was determined from the dry bulb and wet bulb temperatures recorded by a relative humidity meter. The solar radiation data and other meteorological data were obtained from UCE, RTU Renewable Energy Park (Kota).

Instrumentation and experiments

The experiments were conducted during the typical day of winter month. The system is oriented to face south to maximize the solar radiation incident on the dryer. Electronic data logger with six temperature sensors (probes) was used to record temperature. The global solar radiation is measured using pyranometer. Wind speed and exit air velocity at chimney outlet are measured by using Anemometer. The relative humidity of inside and outside of tunnel dryer were measured by using hygrometer. Weight loss of the product during drying period was also measured with an electronic balance. [2]

Experimental setup for evaluation of performance to drying Amla

The performance of the drier was evaluated by conducting tests at no-load and by loading with Amla pulp. In typical day of winter month (December).

Experimental setup for no-load test:

The performance of the solar tunnel dryer was evaluated by conducting test at no-load. The experiment were started at 9:00am and stopped at 5:00pm. The temperatures and the relative humidity of these different parts of the system were measured after every one hour.

Figure: Experimental setup for no load test

Experimental setup for full-load test

Full load testing of solar tunnel dryer was done for evaluating the performance in actual loaded condition .Under this condition the useful heat was extracted and utilized to remove the moisture from Amla (Indian gooseberry).first, Amla was cut into small pulps and then loaded it into solar tunnel dryer.

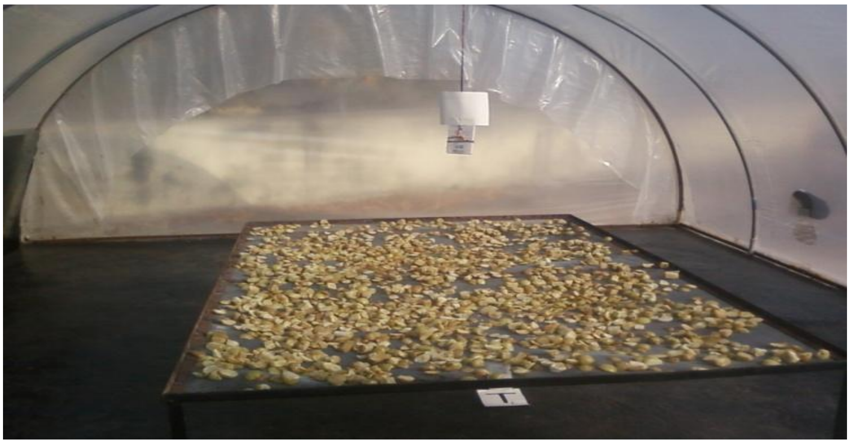


Figure: Measurement of temperature and relative humidity in solar tunnel dryer loaded with Amla(Indian gooseberry)

Figure: Measurement of ambient temperature and relative humidity for Open sun drying of Amla Weight loss of the product during drying period was also measured with an electronic balance. All these data were recorded at one hour interval.

III.RESULT AND DISCUSSION

The experimental data collected during no load and full load testing along with input environmental parameters such as solar insulation, ambient temperature and ambient relative humidity were recorded. The recorded data were analyzed to evaluate the technical and economic performance tunnel for drying Amla pulp.

1. Performance evaluation of solar tunnel dryer for drying amla pulp and comparison with open sun drying.

Performance evaluation of solar tunnel dryer for drying Amla

The performance of solar tunnel dryer was evaluated under no load and full load condition during the month of December for drying amla. The performance of solar tunnel dryer is discussed under the following sub headings.[3]

(i) No load testing of solar tunnel dryer

(ii) Full load testing of solar tunnel dryer

No Load testing of solar tunnel dryer

The performance of solar tunnel dryer without products was carried out in order to find out maximum stagnation temperature attended inside the dryer correspondingly to air flow rate. This is useful for predicting effectiveness of solar tunnel dryer for drying products.

This was evaluated by measuring solar insulation, ambient temperature, air temperature variation at different locations of the solar tunnel dryer, ambient relative humidity, relative humidity inside the dryer, wind velocity and air flow rate inside the dryer.

Solar flux density and temperature

No load testing was conducted with a view to find out temperature variation profile at different locations in solar tunnel dryer. During no load testing. The solar tunnel dryer was empty. The testing on no load was made for consecutive days in the month of December; the maximum average temperature inside the solar tunnel dryer was 47.77^{0}C at 14:00pm hours while the minimum temperature inside the solar tunnel dryer was 33.15^{0}C at 9:00am on a typical day in the month of December. While maximum ambient temperature was 34.8^{0}C at 14:00pm and the minimum ambient temperature was 23.1^{0}C at 9:00am hours on that day. It was also observed that the maximum and minimum solar insulation in this month was 685W/m^2 at 14:00 hours and 458W/m^2 at 9:00 hours, respectively.

The average air temperature rise inside the solar tunnel dryer over ambient air temperature was 12.97^{0}C during no load condition. It is observed from figure.

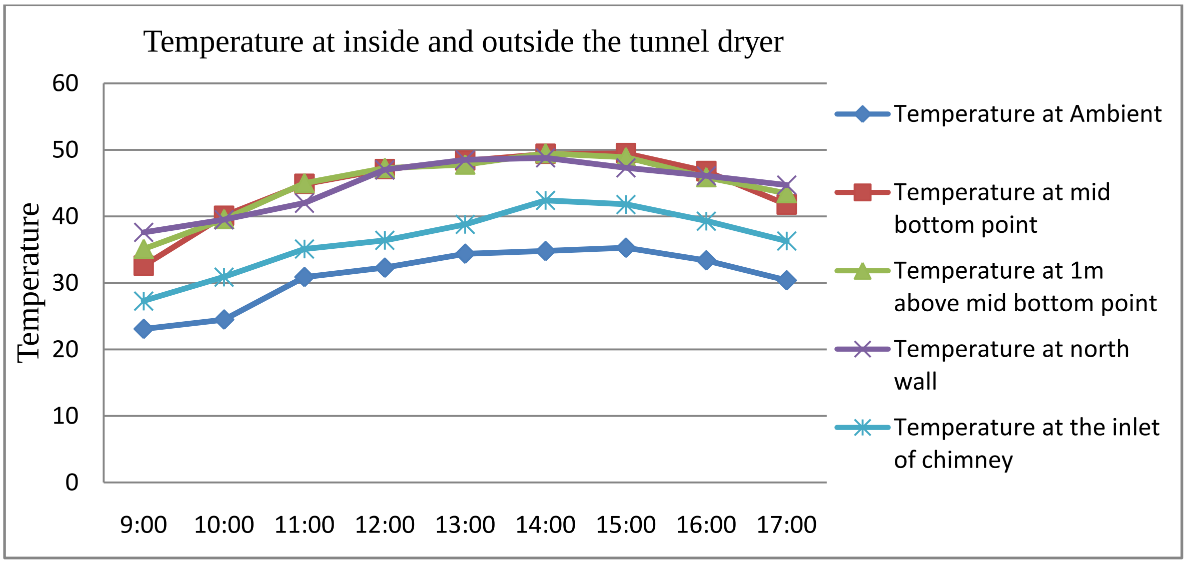


Figure: Variation of solar radiation, ambient temperature and temperature at different location in solar tunnel dryer with time at no load condition.

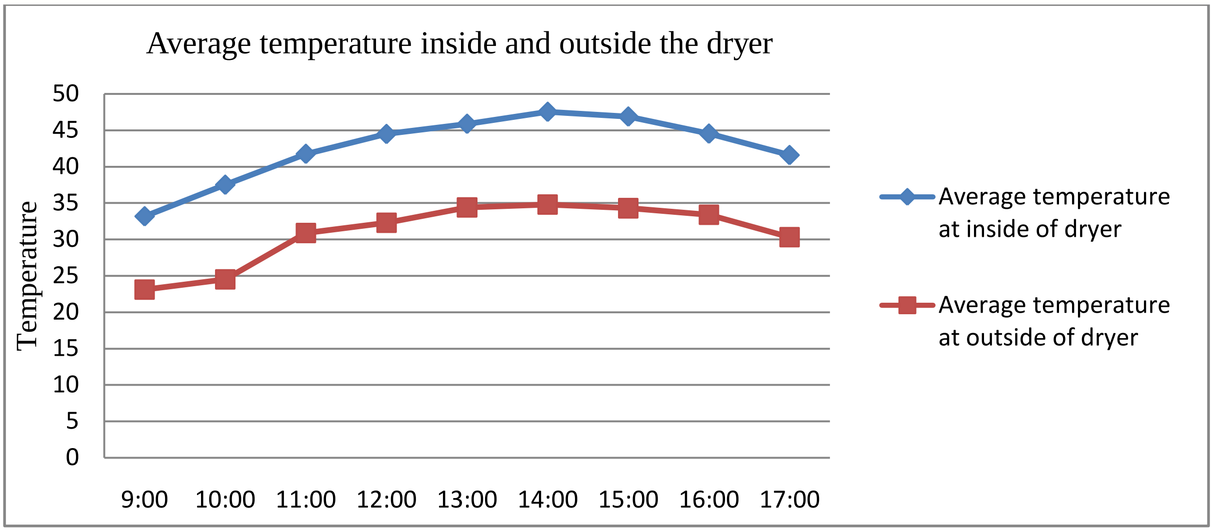


Figure: Variation of average temperature inside and outside the solar tunnel dryer at no load.

Variation of Relative Humidity

The relative humidity varied from time inside the dryer depending on weather conditions. The variation of relative humidity at different location to the inside of the tunnel dryer for the month of December are given in graph.

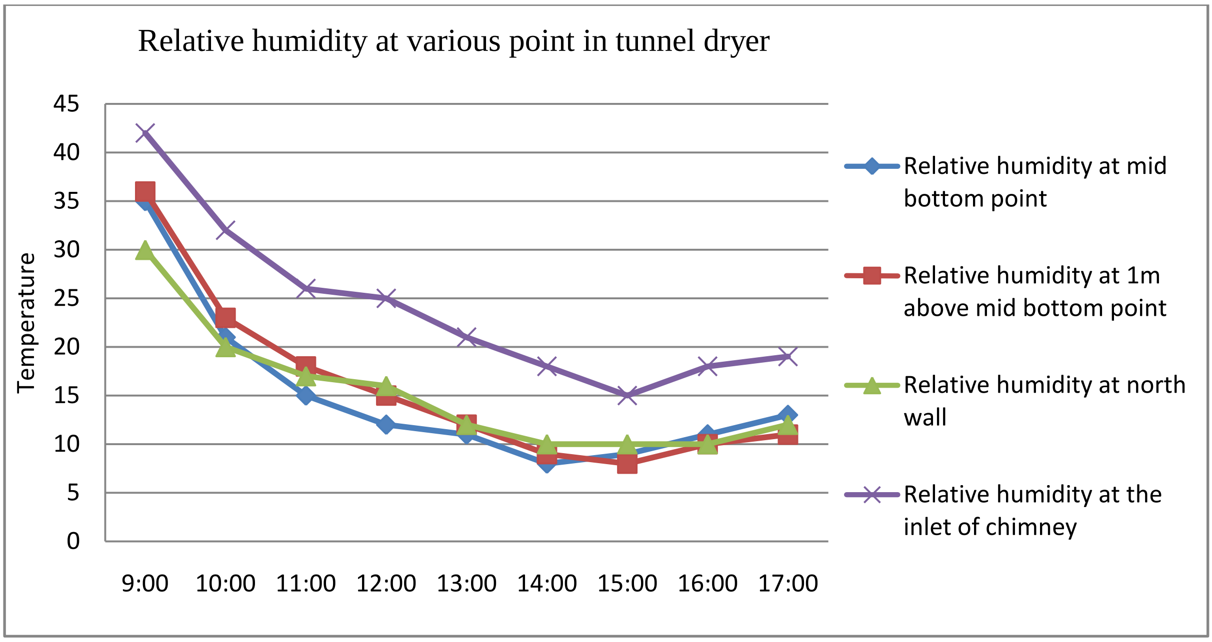


Figure5.4: Variation of relative humidity at different points inside the tunnel dryer at no load.

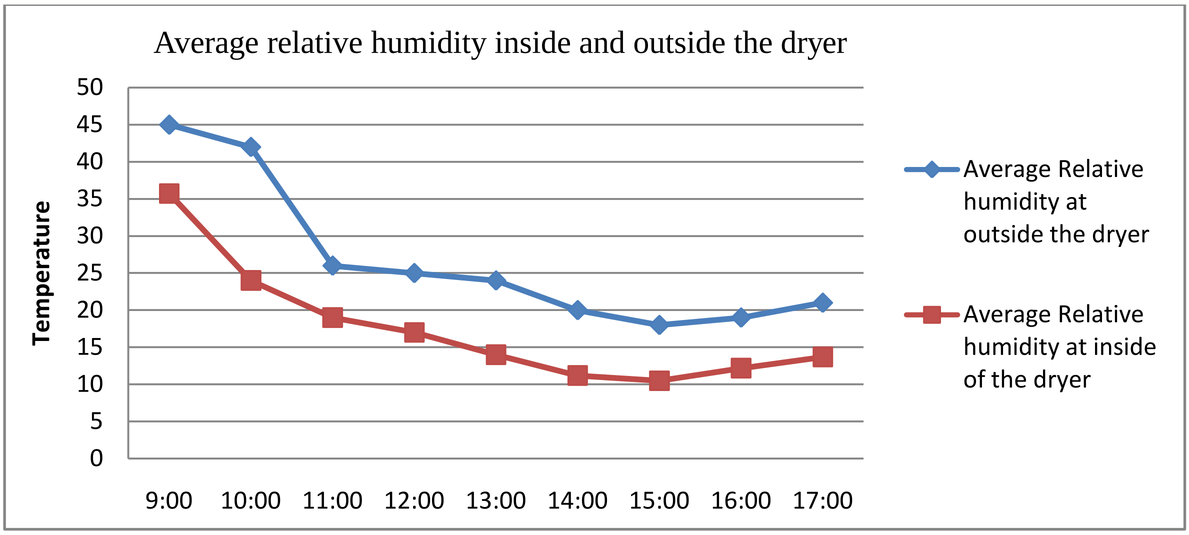


Figure5.5:Variation of average relative humidity inside and outside the Solar Tunnel dryer at no load condition in winter month.

As shown in figure the maximum relative humidity inside the tunnel was 35.7% at 9:00hrs while minimum relative humidity was 10.5% at 15:00hrs in the month of December. At the same time Maximum ambient relative humidity was 45% at 9:00hrs while minimum relative humidity was 18% at 15:00hrs respectively.

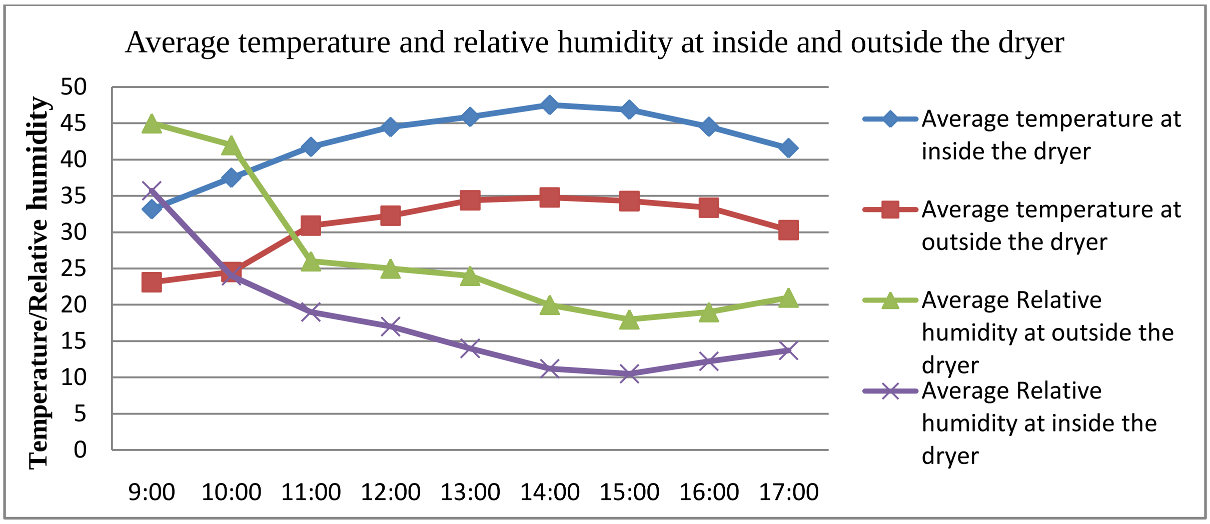


Figure: Average dryer temperature and relative humidity at no load condition.

Variation of Air Flow Rate

The air flow rate inside the tunnel dryer was depending on air temperature with flow of air. The variations of air flow rate for the month of December under no load condition are given in figure.

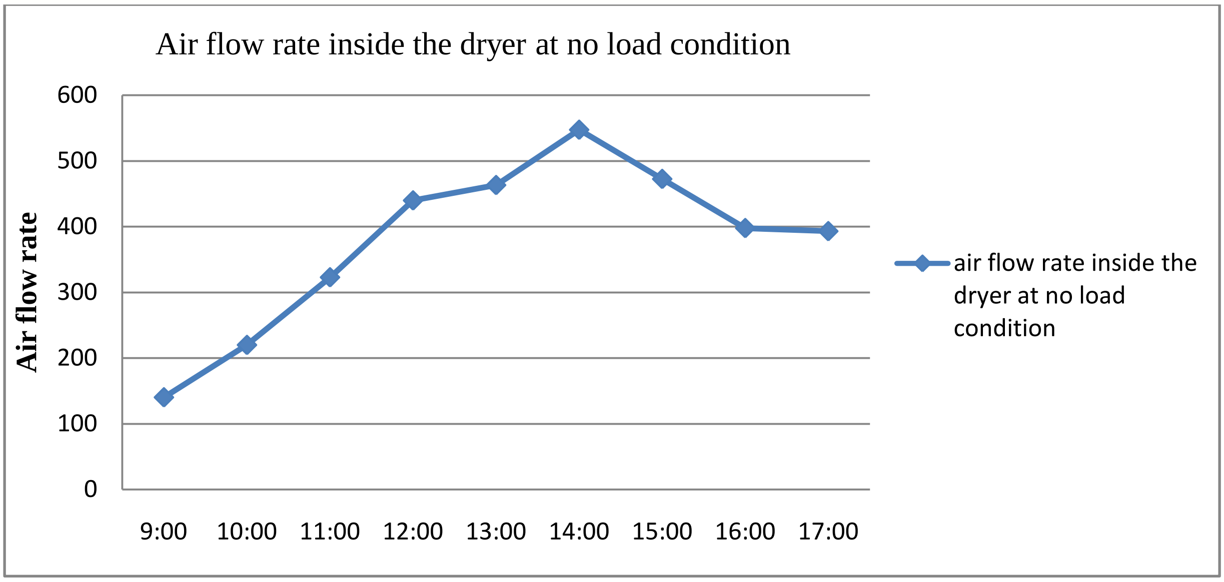


Figure: Variation of air flow rate inside the tunnel dryer with time

Figure shows that the maximum air flow rate inside the tunnel was 547.5m^3/h at 14:00hr while minimum air flow rate was 140.4m^3/h at 9:00hr in the month of December. The average air flow rate was 322.9m^3/h during study.

Variation of solar collector efficiency

The collector efficiency was calculated under no load condition for the month of December. The observation and computation are given in figure. The heat received by the collector ranged from 10870.164 to 13670.774kj/hr in the month of December.

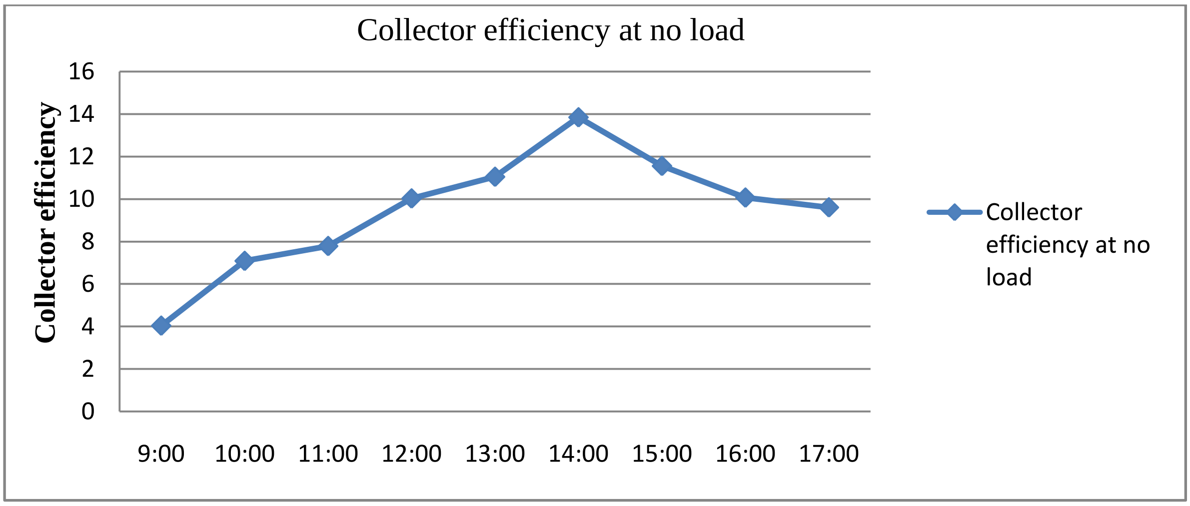


Figure: Collector efficiency of tunnel dryer at no load condition

The maximum heat received was 16257.7792kj/h at 14:00 hours because of higher solar insulation. The average heat received was 13988.5kj/hr. The heat gained by the air ranged from 438.18 to 1375.87kj/hr in the month of December (figure) the maximum collector efficiency of 13.84 percent was attained at 14:00 hours. The average collector efficiency was 9.88 percent.

Full Load testing of solar tunnel dryer

Full load testing of solar tunnel dryer was made for evaluating the performance in actual loaded condition. In full load testing, 10kg of Amla pulp was placed in solar tunnel dryer and 3kg (sample) of Amla pulp was placed in open air for drying for comparison purpose. The performance evaluation test includes measuring solar insulation, ambient temperature, ambient relative humidity, wind velocity, air flow rate inside the dryer, air temperature and relative humidity inside the solar tunnel dryer. During full load testing, two days are required for drying total amount of Amla pulp in solar tunnel dryer from moisture content of 376.16 to 6.14 percent (d.b) the testing on full load was conducted for two consecutive days in the months of December, respectively.

Solar flux density and temperature

As shown in figure the maximum temperature inside the solar tunnel dryer was 46.07^{0}C at 15:00 hours while the minimum temperature inside the solar tunnel dryer was 30.5^{0}C at 9:00hours in typical day in the month of December against the maximum ambient temperature and minimum ambient temperature of 32.6^{0}C and 20.6^{0}C, respectively. It was also observed that the maximum and minimum ambient solar insulation in this month was 643W/m^2 at 14:00hours and 413W/m^2 at early morning 9:00hours, respectively.

The average air temperature rise inside the solar tunnel dryer over ambient air temperature was 13.4^{0}C during full load condition of amla drying. It is observed from figure that air temperature rise inside the dryer increased linearly with the increase in solar radiation with time. The following regression equation was developed for air temperature rise inside of the solar tunnel dryer with solar radiation.

$\Delta T = 7.1822 + 0.0114G$

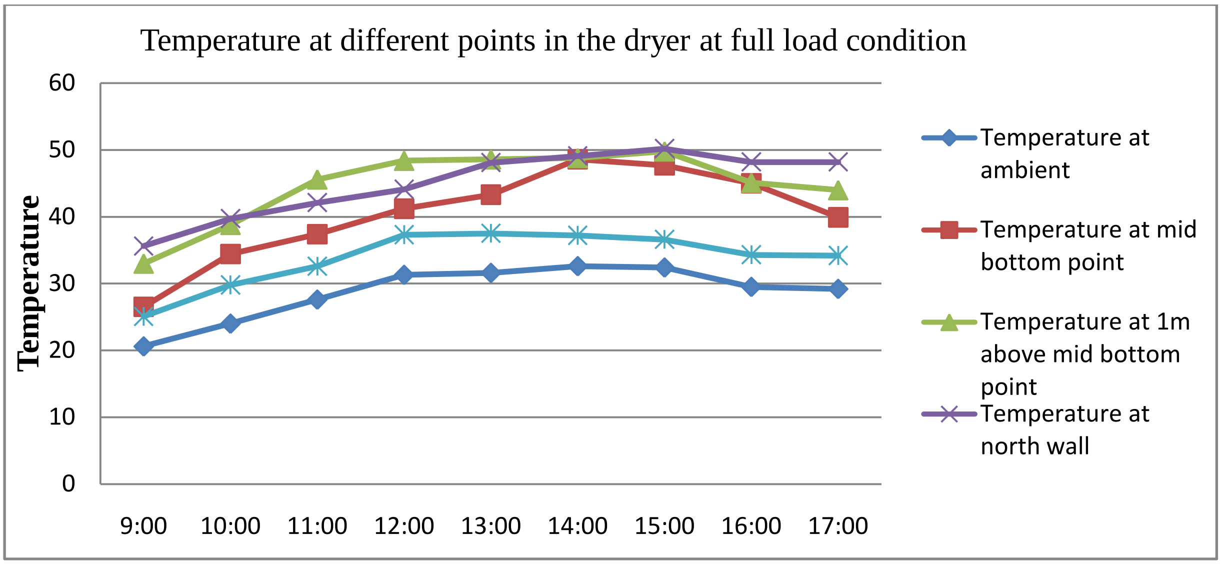


Figure: Variation of ambient temperature and temperature at different locations in solar tunnel dryer at full load condition.

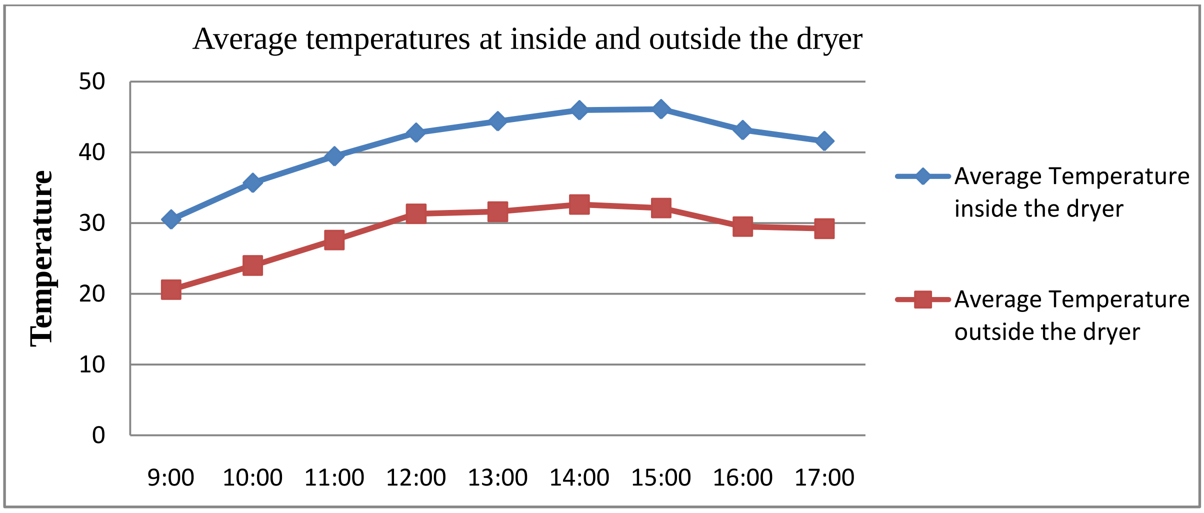


Figure: Average temperature inside and outside of solar tunnel dryer in full load condition.

Variation of relative humidity

The variation of relative humidity in full load condition for the months of December under this study on daily basis for outside and inside condition are given in graph.

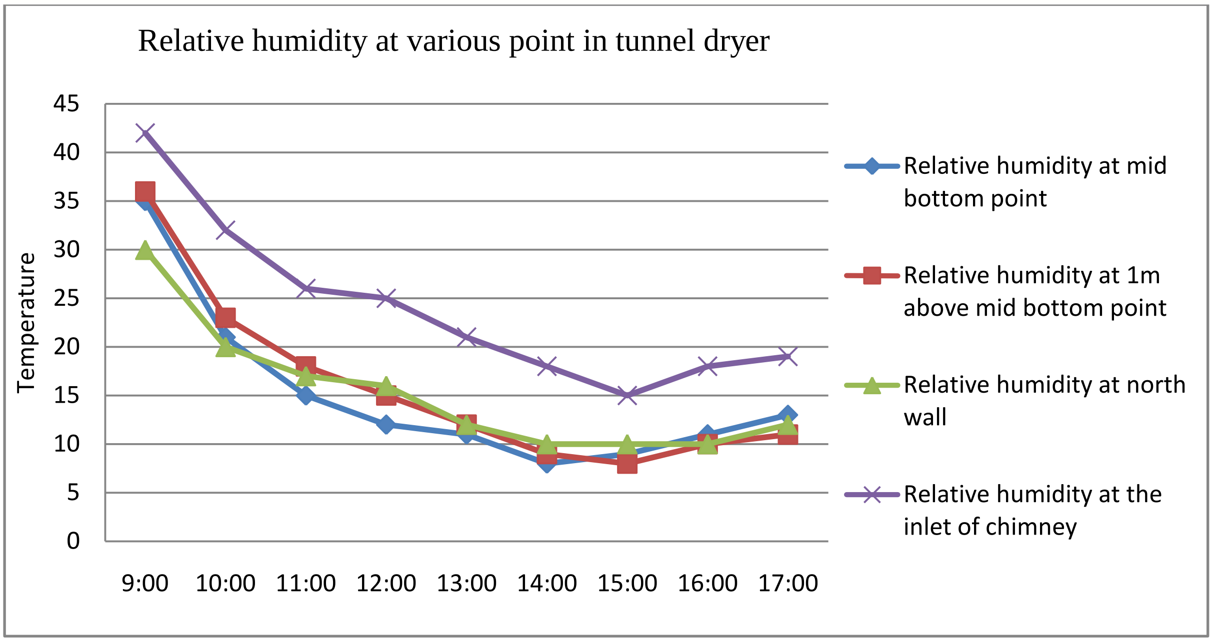
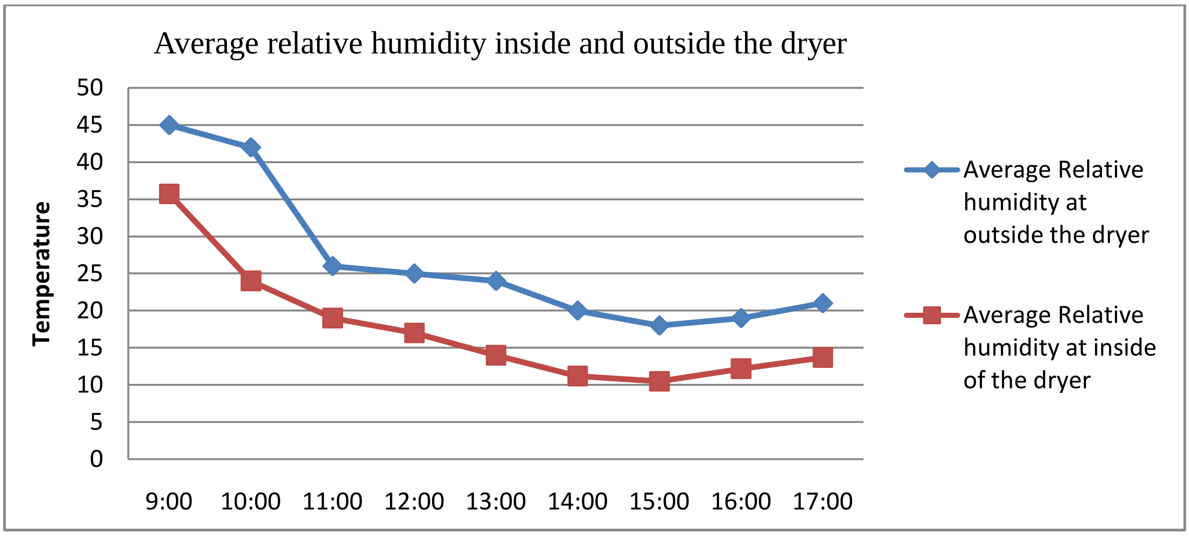


Figure5.4: Variation of relative humidity at different points inside the tunnel dryer at no load.



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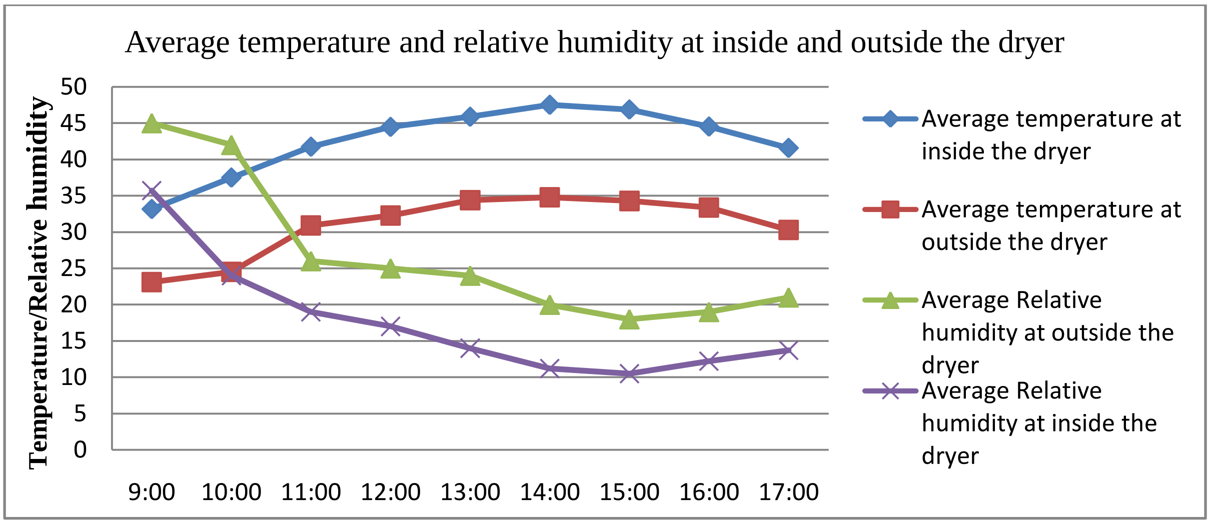
As shown in figure. The maximum relative humidity inside the tunnel was 38.7 percent at 9:00hrs, while minimum relative humidity was 16.50 percent at 15:00hrs in the month of December. Maximum ambient relative humidity in this month was 52 percent at 9:00hrs while minimum ambient relative humidity was at 15:00hrs respectively 23 percent.



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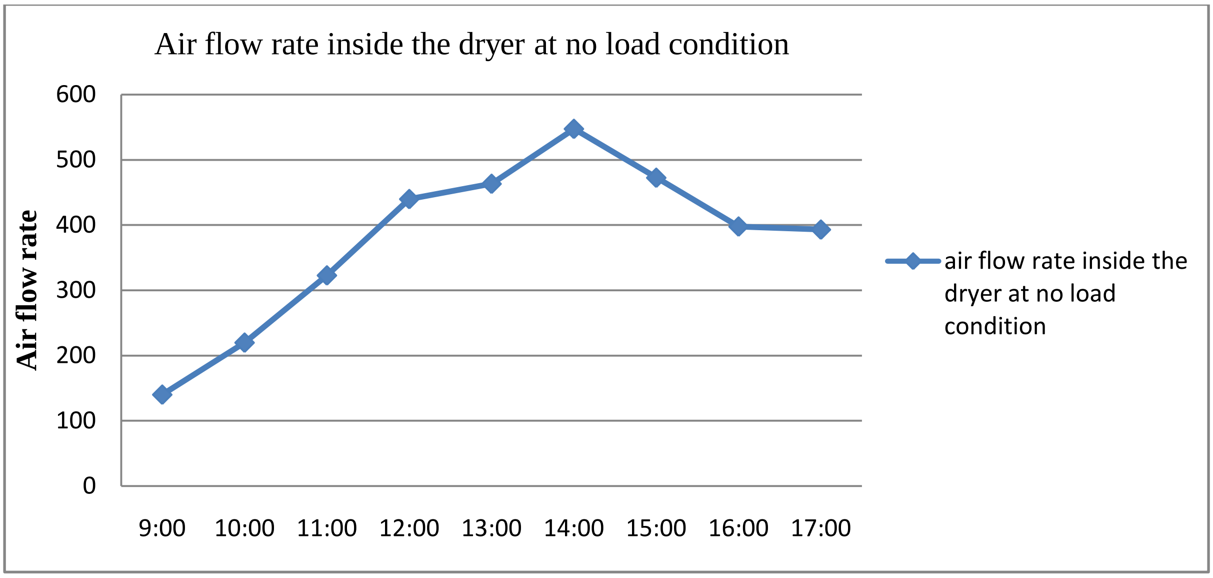

Figure: Variation of air flow rate inside the tunnel dryer with time

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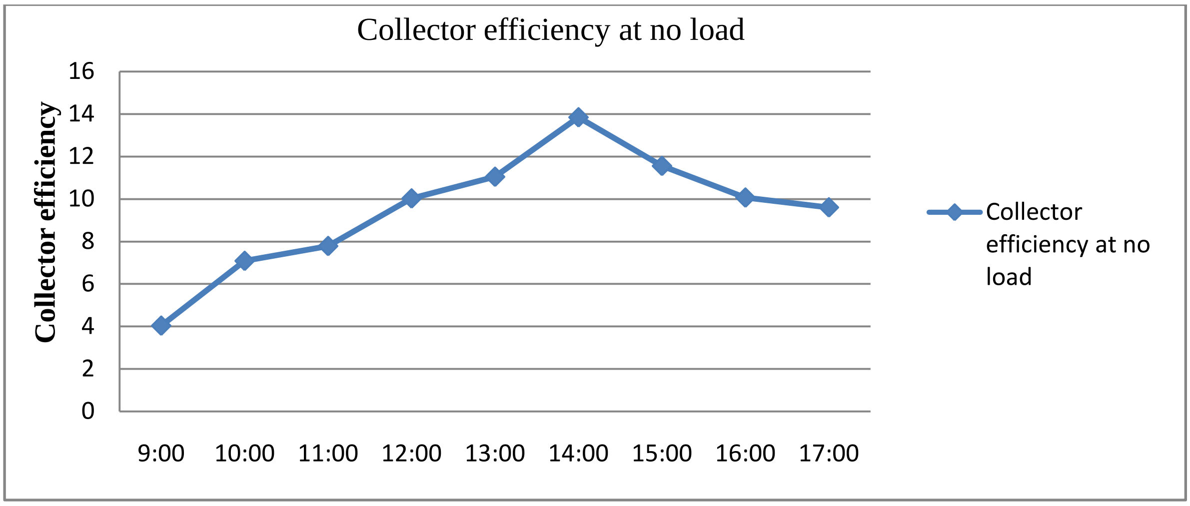

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Solar flux density and temperature

As shown in figure the maximum temperature inside the solar tunnel dryer was $46.07^{0}C$ at 15:00 hours while the minimum temperature inside the solar tunnel dryer was $30.5^{0}C$ at 9:00hours in typical day in the month of December against the maximum ambient temperature and minimum ambient temperature of $32.6^{0}C$ and $20.6^{0}C$, respectively. It was also observed that the maximum and minimum ambient solar insulation in this month was $643W/m^{2}$ at 14:00hours and $413W/m^{2}$ at early morning 9:00hours, respectively.

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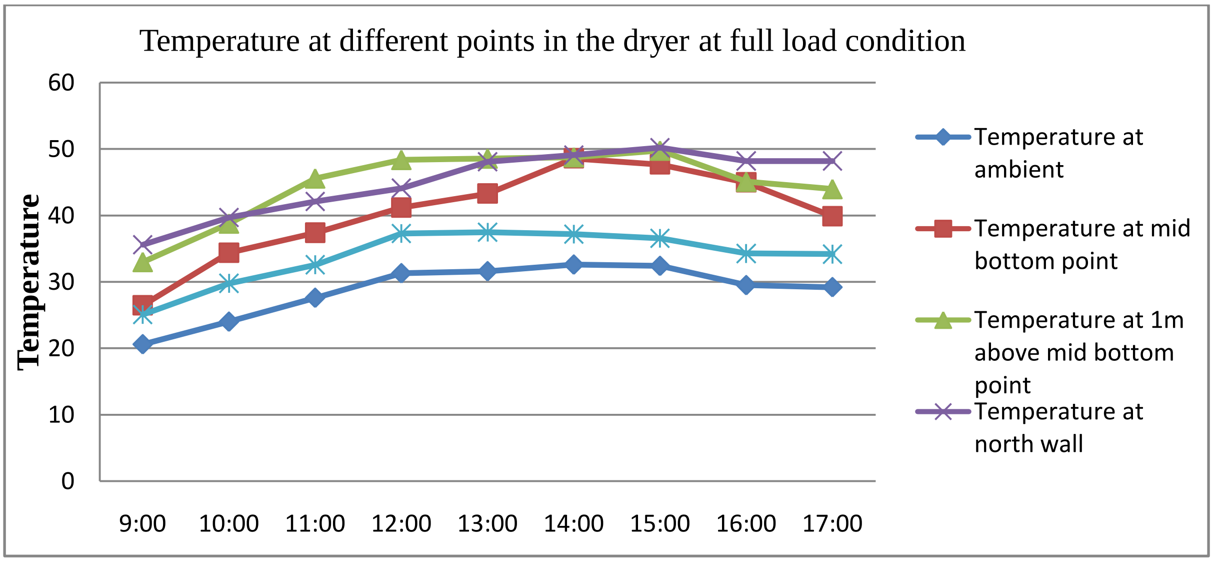

Figure: Variation of ambient temperature and temperature at different locations in solar tunnel dryer at full load condition.

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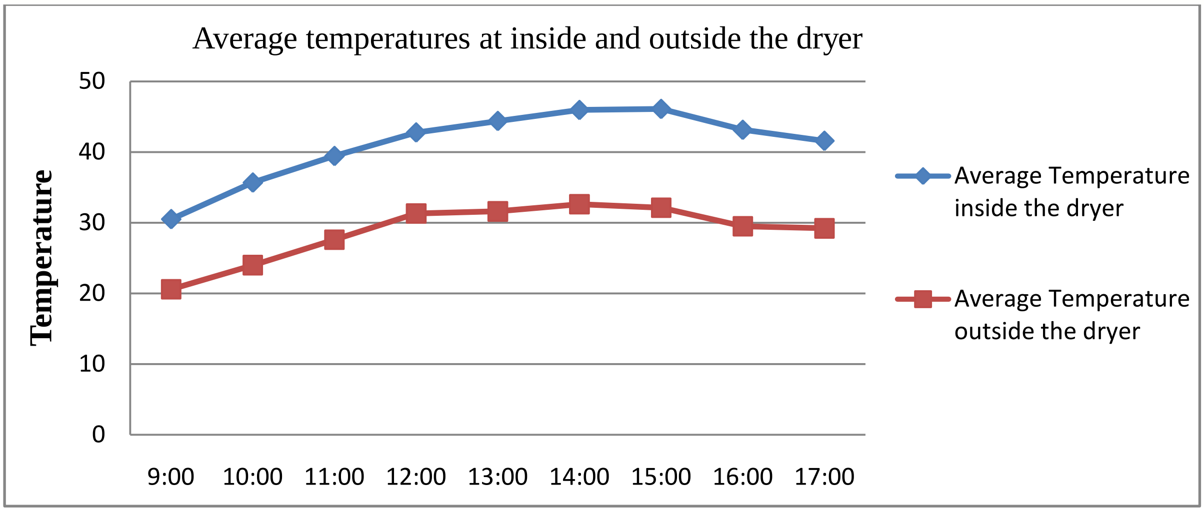

Figure: Average temperature inside and outside of solar tunnel dryer in full load condition.

Variation of relative humidity

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As shown in figure. The maximum relative humidity inside the tunnel was 38.7 percent at 9:00hrs, while minimum relative humidity was 16.50 percent at 15:00hrs in the month of December. Maximum ambient relative humidity in this month was 52 percent at 9:00hrs while minimum ambient relative humidity was at 15:00hrs respectively 23 percent.

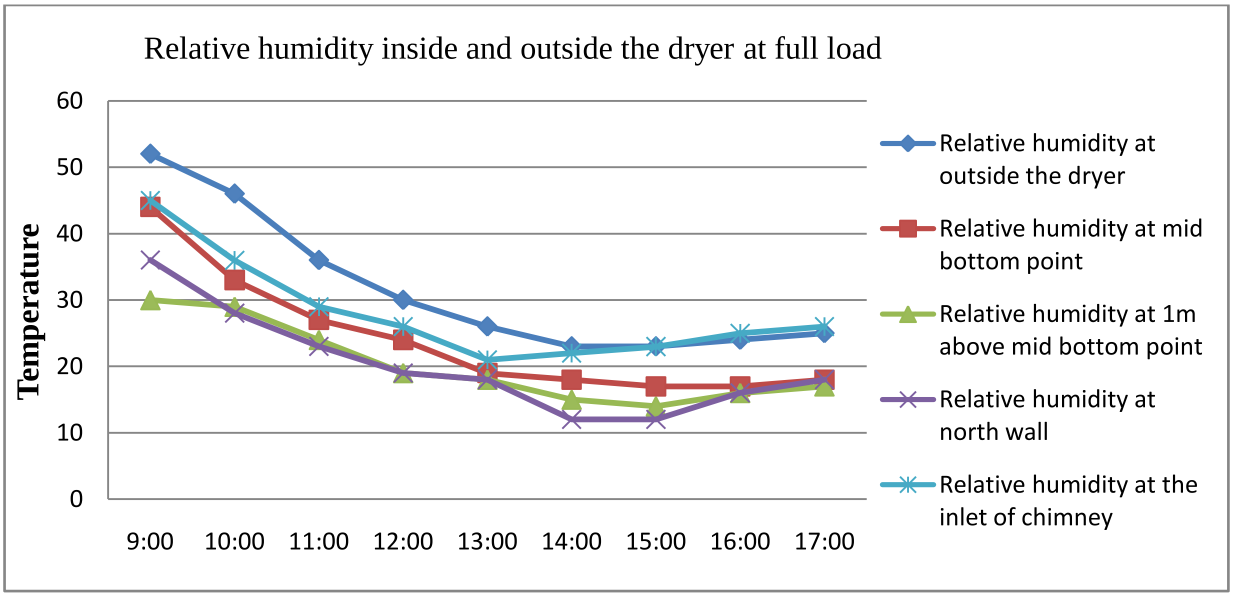

Figure: Variation of relative humidity at different location at full load condition.

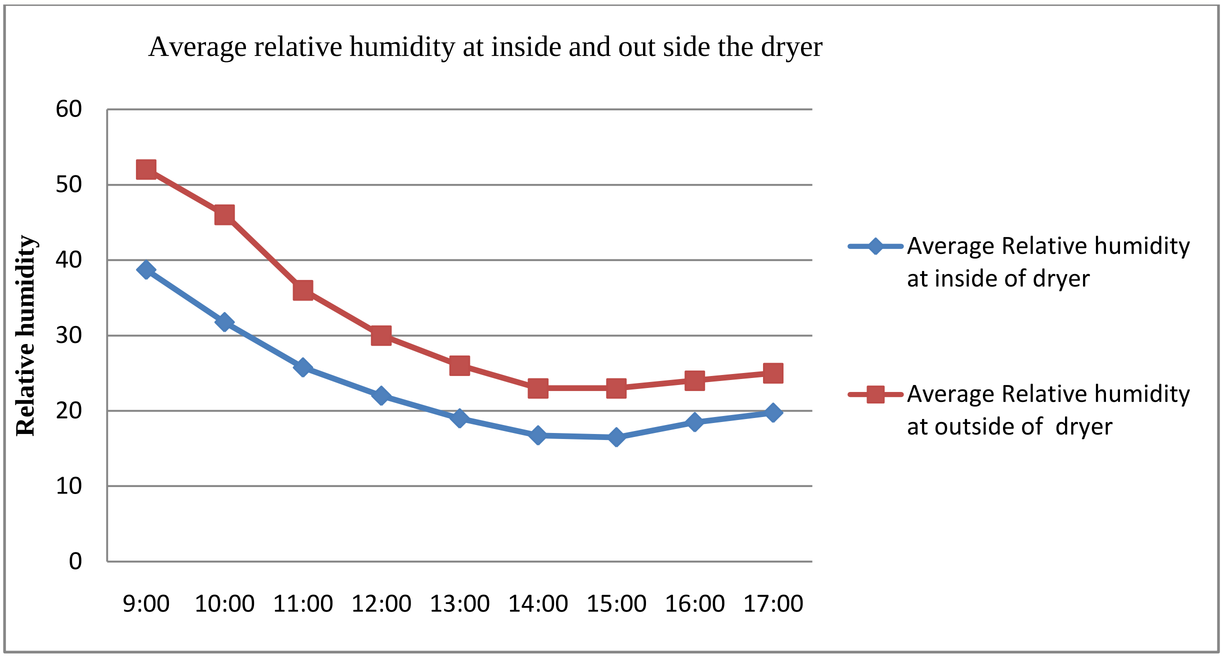

Figure: Ambient and Average dryer Relative humidity during full load condition.

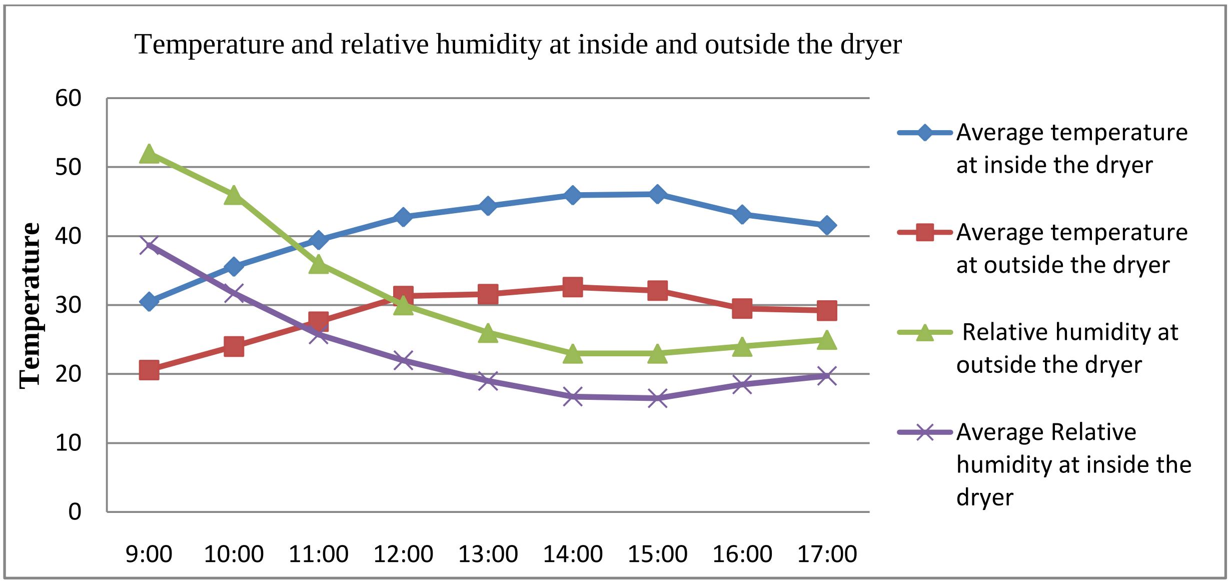

Figure: Average Temperature and Relative humidity during full load condition.

Variation of air flow rate

The variation of air flow rate for the months of December under full load condition are given in

The maximum air flow rate inside the tunnel was 538.2m^3/hr at 14:00hrs while minimum air flow rate was 135.7m^3/hr at 9:00hrs in the month of December. The trend of result is illustrated in figure5.16.

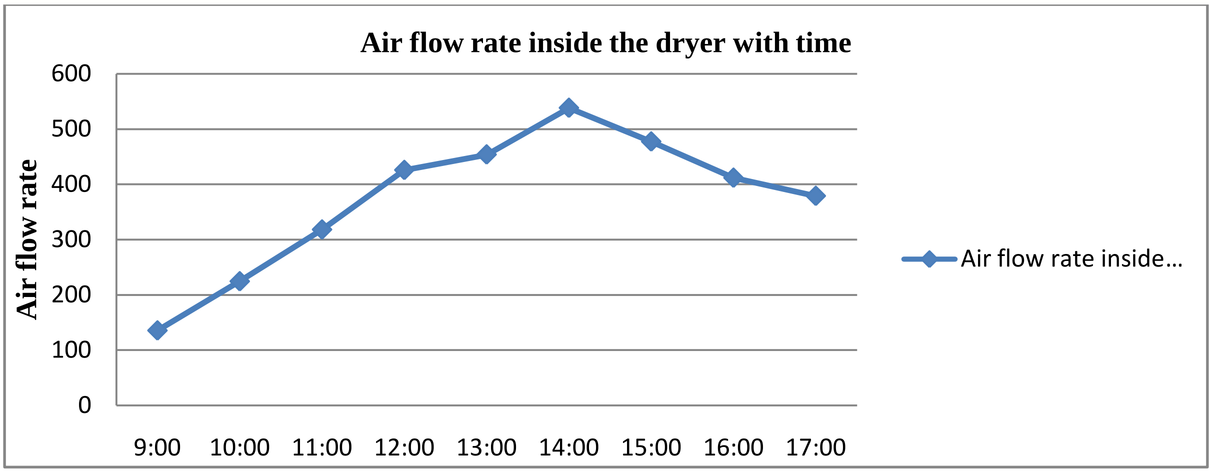

Figure: Variation of air flow rate at full load condition for Amla drying in winter.

Variation of moisture content

The comparison of moisture content of amla pulp in the solar tunnel dryer with conventional sun drying for a typical experimental run were conducted in the months of December at installation of Department of Mechanical Engineering UCE, RTU, Kota as Shaw in figure.

Figure: Amla drying in open sun drying winter month (December)

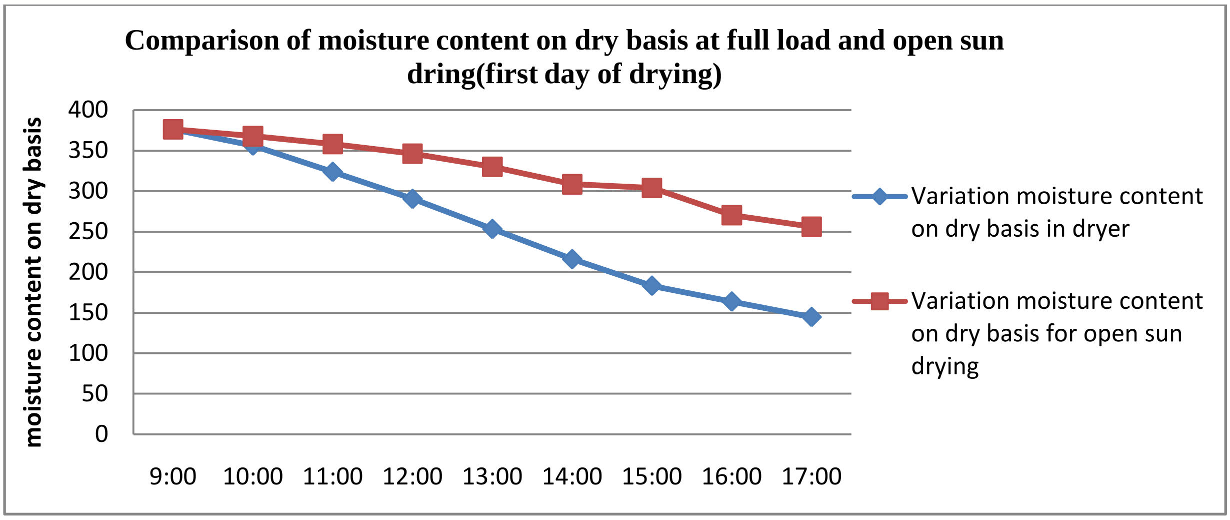

Figure: Comparison of moisture content on dry basis at full load condition and Open sun drying during first day of drying

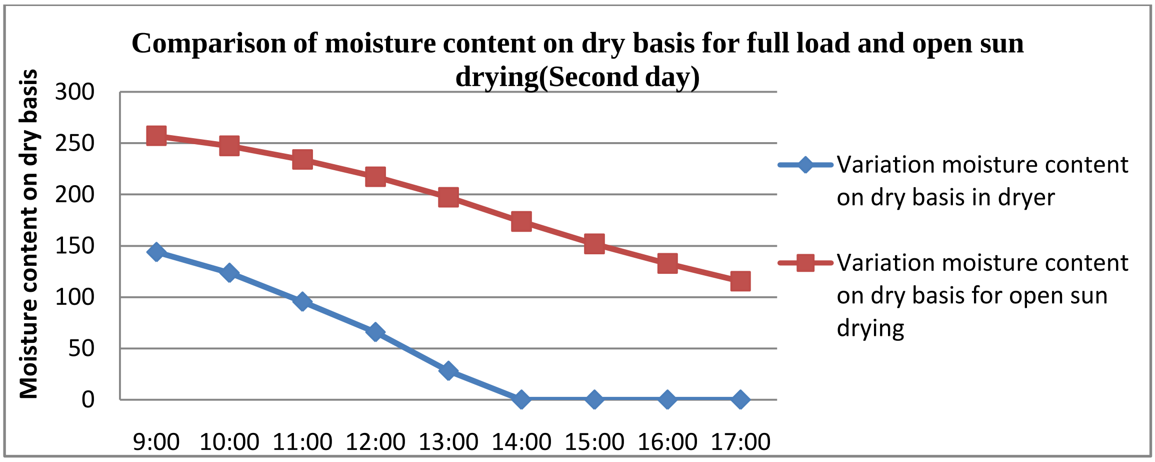

Figure: Comparison of moisture content on dry basis at full load condition and Open sun drying during second day of drying

Amla pulp was dried from a moisture content of 376.19% (d.b.) to 6.14% (d.b.) in 14 hours of drying in solar tunnel dryer as compared to 25 hours of drying in open sun drying.

Figure indicates that the moisture content of amla pulp was reduced from 376.19 to 144.85% on dry-basis on first day drying for the month of December. Same as during second day of drying moisture content reduced from 143.90 to 6.14%, at the end of drying, while in open air it was 173.6%. It was also noted that about 44.95% moisture was removed on first day of drying while 43.73% moisture was removed on second day of drying.

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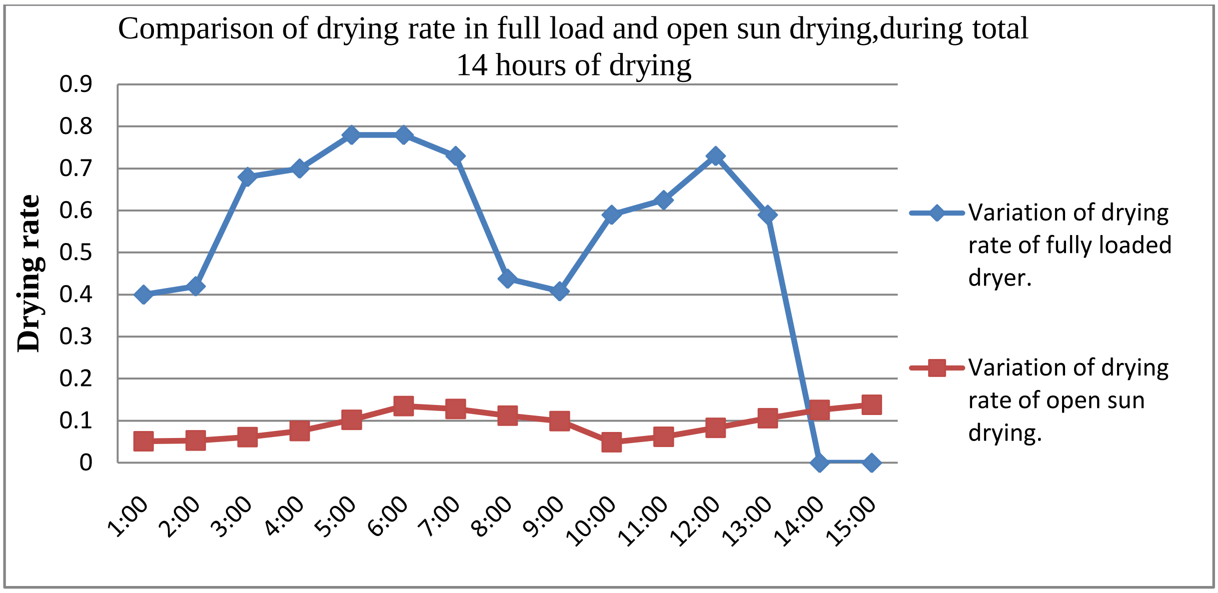

Figure5.21: Variation of drying rate of fully loaded tunnel dryer and open sun drying with time (14 hours of Amla drying)

The variation of drying rate with drying time (14hours of Amla drying) is shown in figure. for solar tunnel dryer and open sun drying for a typical day of the month of December. It was observed that the drying rate of tunnel dryer for the first two hour was 0.400kg/hr to 0.420kg/hr and at the same time drying rate of open sun drying was 0.051kg/hr to 0.053kg/hr at the end of the first day of drying, drying rate reduce to 0.408kg/hr in tunnel dryer and 0.099kg/hr in open sun drying. Again second day of drying, drying rate increases as shown in figure. It was observed that drying rate follows the pattern of radiation. The drying rate increased up to 14 hours and then decreases on each day of drying.

Variation of solar collector efficiency

The heat received, heat gained and collector efficiency were calculated (as per appendix A) under full load condition for the month of December.

The observation and computation are given in table5.21 and figure5.23. The heat received by the collector ranged from 9802.135 to 13196.0952kj/h in the month of December. The maximum heat received was 15260.9518kj/h at 14:00 hours because of higher solar insulation. The average heat received was 13196kj/h.

Heat received by dryer varies with solar insulation in full load condition of amla drying. It also depends on collector area. And collector area depends on design criteria for amla drying. Here collector area 41.078m^2 was found by calculation.The heat gained by the air ranged from 1149.699 to 4012.414kj/h in the month of December (figure5.23) the maximum collector efficiency of 14.58 percent was attained at 14:00 hours. The average collector efficiency was 11.63 percent.

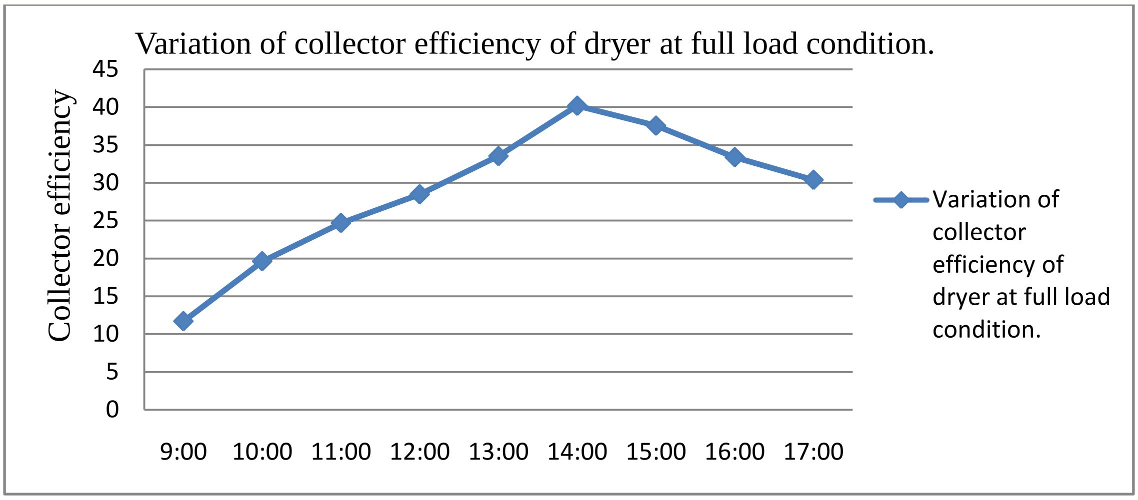

Figure5.22: - Collector efficiency of solar tunnel dryer at full load condition

Final results

The drying process was stopped after no further change in mass was observed. At this point, moisture content decreased from 376.1% to 6.14% on dry basis (79% to 21.93% wet basis) using air temperature in the range 32 to 50^{0}C in solar tunnel dryer over a period of 14hours. Final quality of Amla pulp inside the tunnel dryer after 14hours of drying period, shown in figure.

Figure5.24: Final quality of Amla pulp.

Final quality of Amla pulp for open sun drying after 14hours of drying period, shown in figure.

Figure: Final quality of Amla pulp for open sun drying.

From the figure. The final quality of Amla pulp for drying through tunnel dryer was quite satisfactory as compared to open sun drying method. The drying of Amla in the STD was distinctly faster than the OSD. The overall drying efficiency of STD is estimated to be 14.12% during Amla drying. The Amla dried in STD had softer texture, had good odor and a bright attractive color. On the other hand, the Amla dried in open sun showed rough texture, bad odor, and whitish yellow patches on the surface.

IV.CONCLUSIONS

Renewable energy sources are mostly indigenous and traditional sources, which are regenerated during the annual solar cycle, Technologies for their conversion and utilization are environmentally friendly. Experience in similar solar dryer for fruits and vegetables proved that solar drying can be attractive method for food preservation and also for a commercial proposition. Drying conditions in Kota, Rajasthan, India are very favorable, and initiation of a solar dryer can save conventional fuel.

- A natural convection solar tunnel dryer was designed and Constructed based on preliminary investigation of ayourvedic Product (Amla) drying under controlled conditions. The designed dryer with a collector area of $40.71m^2$ is expected to dry 100-150kg wet Amla(Indian gooseberry) from 376.1% to 6.14% on dry basis (79% to 21.93% wet basis) in two days under ambient conditions during winter month (December).

- At the same time in open sun drying, sample of (3kg wet Amla) were drying from 376.1% to 173.6% on dry basis (79% to 63.46% wet basis).

- The performance of solar tunnel dryer for drying Amla was evaluated through no-load and full-load conditions tests in the winter month. The air temperature inside the solar tunnel dryer was higher than outside by 14–15^0C. No constant rate drying period was observed.

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