Experimental and Comparison Studies on Drying Characteristics of Grapes in a Solar Tunnel Greenhouse Dryer Coupled with and without Biomass Backup Heater

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Abstract*— A natural convection solar tunnel greenhouse dryer coupled with biomass heater was designed and developed in Nallampalli region of Pollachi, Tamil Nadu (India) and also a natural convection solar tunnel greenhouse dryer without biomass heater was designed and developed in Negamam region of Pollachi, Tamil Nadu (India) for carrying out the experimental and comparison studies of drying characteristics of grapes during the month of May, 2014. About 50kgs of fresh and good quality grapes were loaded into those dryers and it was repeated for three trails. The mass of fuel added to the biomass heater was about 7.5kg/hr. The biomass heater was ignited when there is a fall in sunshine (after 5PM) in order to maintain the temperature inside the dryer and the fuel used is the remains of the coconuts such as coconut fronts, coconut husk, coconut shell and firewood. The solar tunnel dryer coupled with the biomass heater dried the grapes which has an initial moisture content of 80% (w.b.) to a final moisture content of 10% (w.b.) over a time period of 30 hours whereas the solar tunnel greenhouse dryer without the biomass heater took 55hours for reducing the moisture content of the grapes to the same level. The reduced drying time in the solar tunnel greenhouse dryer coupled with the biomass heater than that of the dryer without the biomass heater is due to the effect of biomass heater that is responsible for the constant increase in temperature inside the dryer which is made possible by supplying sufficient heat during the night time (after 5PM) where there would be a drop in sunshine. Also, the quality of the grapes obtained from the solar tunnel greenhouse dryer coupled with biomass heater was found to be superior to that of the grapes obtained from the solar tunnel greenhouse dryer without the biomass heater which is due to the high temperature and low relative humidity prevailed all the time inside the dryer irrespective of fall in sunshine.

***Index Terms*—Biomass heater, drying time, grapes, moisture content, open sun drying, product quality, solar tunnel greenhouse dryer, sunshine.**

I. INTRODUCTION

Grapes are well known for its medicinal properties and are grown under a variety of soil and climatic conditions in three distinct agro-climatic zones in India. The total world production of grapes is estimated to be about 63 million tonnes, which amount to about 16% of total fruit production. About 20% of the table grape production is exported as compared to 9% export of other fruits. The area, production and the productivity of grapes in India is 42,600 ha, 1.1 million tonnes and 25.4 tonnes/ha, respectively (Anonymous, 2003). Among fruits, grapes are the most perishable food stuffs, when compared with other agricultural products. They can easily get affected by microorganism resulting in poor quality which ultimately leads to wastage of food stuffs. In order to avoid the wastage and to prolong the shelf life of grapes, the moisture content of grapes can be reduced from an initial moisture content of 80% (w.b.) to a final moisture content of 10% (w.b.). Drying of fruits and vegetables is one of the oldest methods of food preservation and it is being practiced still nowadays. In order to overcome the quality degradation of the dried products, it is important to reduce the fungal and bacterial infections by reducing the moisture content of the products to a safer level. Dehydration of products not only helps in preventing the fungal and bacterial infections but also helps in reducing the size of the product thereby minimizing packaging costs and transportation costs. The most traditional method of drying is the Open Sun Drying (OSD) method where the products will be spread over the floor of the drying yard. But this process is a time consuming process and there will be degradation in quality of dried products due to the low atmospheric temperature and high relative humidity of the surrounding air that leads to fungal and bacterial infections, contamination by insects, damage by rodents & birds and windborne problems like dust & dirt. In addition, this OSD method requires a skillful person to carry out the process effectively thus leading to the high labour cost and demand of manpower. To overcome the practical difficulties of OSD method, a natural convection solar tunnel greenhouse dryer was designed and developed in Negamam region of Pollachi (Tamil Nadu), India which basically operates on the principle of greenhouse effect in which all the radiations emitted by sun will be absorbed by this dryer since it will be wrapped with the polyethylene sheet of 200 microns that enhances the greenhouse effect. The radiations absorbed will not be emitted back and thus acts as a solar trap. This solar trap is responsible for the steady increase of temperature inside the dryer. A greenhouse heating system is used to increase the thermal energy storage inside the greenhouse during the day or to transfer excess heat from inside the greenhouse to the heat storage area. This heat is recovered at night to satisfy the heating needs of the solar tunnel greenhouse dryer. Moreover, the solar tunnel greenhouse dryer overcomes the effects of

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bacterial and fungal infections, contamination by insects, damage by birds and animals etc. Also this dryer helps in drying the products at an earlier time than the open sun drying method thereby minimizing drying time. Further, the quality of red chillies obtained from the solar tunnel greenhouse dryer was found to be superior to that of open sun dried red chillies. But even in this dryer, arises a problem when there was a fall in sunshine. The dryer cannot dry the products effectively after 5PM of a day where there will be a drop in sunshine and temperature. The heat recovery from greenhouse effect during time won't last for a longer time leading to an extended drying time but not more than open sun drying method. In order to overcome this defect, a natural convection solar tunnel greenhouse dryer coupled with biomass heater was designed and developed in Nallampalli village of Pollachi, Tamil Nadu (India). The biomass heater coupled to the dryer will supply sufficient heat for an effective drying of products inside the dryer when there is a fall in sunshine even at night time. The biomass can be ignited with any type of fuel such as coconut fronts, coconut shells, coconut husk etc. and it should be loaded for every one hour interval (after 5PM). By using this type of biomass coupled dryer, the products can be dried yet at an earlier time than the solar tunnel greenhouse dryer without the biomass heater.

This study investigates and compares the drying characteristics of grapes dried in the open sun drying method and in the solar tunnel greenhouse dryer with and without biomass heater and thereby optimizing the best dryer for drying of products.

II. EXPERIMENTAL SECTION

Experiments were carried out under meteorological conditions of Pollachi (latitude, 10.39°N; longitude, 77.03°E) in India during the month of May, 2014. On the basis of measurement, sunshine duration at this location was measured to be about 11 h per day. However, potential sunshine duration is only 8 h per day (9.00 am- 5.00 pm) based on higher solar intensity.

III. SOLAR TUNNEL GREENHOUSE DRYER (STD)

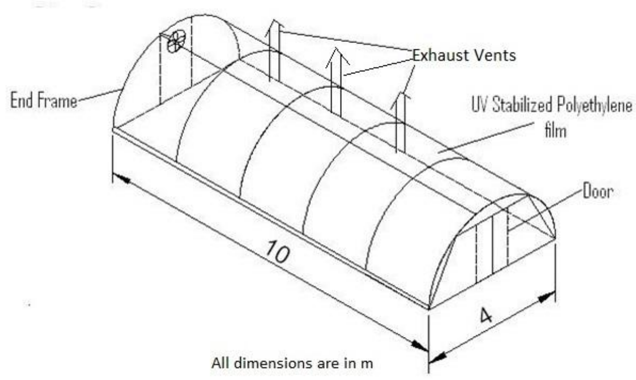

Fig. 1 Solar tunnel greenhouse dryer

An STD (Fig.1) as a community model solar tunnel greenhouse drier [4 m (W) x 10 m (L) x 3 m (H) at centre] was designed and constructed at Negamam village using locally available materials. Semicircular portion of drier was covered with UV (200μ) stabilized polyethylene film. No post was used inside the greenhouse, allowing a better use of inside space. Inside drier, cement flooring was coated with black paint to improve its performance. STD is provided with metallic racks for keeping the products in layers for drying. To investigate the influence of parameters affecting the performance of solar tunnel drier, various measuring devices were installed. A pyranometer was used to measure the incident solar radiation falling on the roof of the solar tunnel green house dryer. Thermocouples were used to measure air temperature at four different points inside the dryer and ambient air. To measure the relative humidity of the air, a hygrometer was employed. The electric signals from the thermocouples and the pyranometer were recorded with an 8-channel data logger. A sling psychrometer was also used to measure the dry bulb temperature and wet bulb temperature of the air.

IV. SOLAR TUNNEL GREENHOUSE DRYER COUPLED WITH BIOMASS BACKUP HEATER

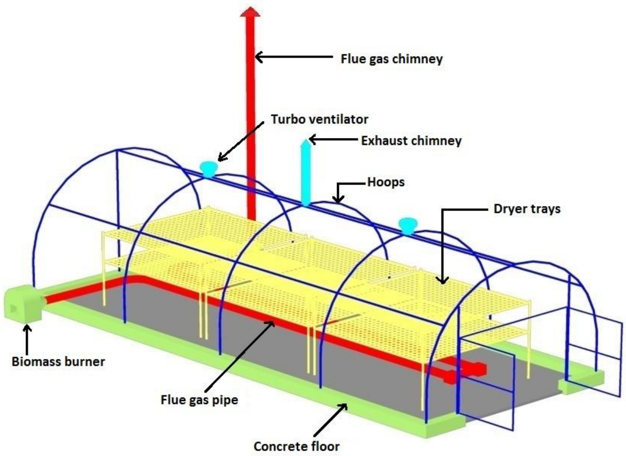

Fig. 2 Solar tunnel greenhouse dryer coupled with biomass backup heater

An STD (Fig.2) as a community model solar tunnel greenhouse drier [4 m (W) x 10 m (L) x 3 m (H) at centre] was designed and constructed at Nallampalli village using locally available materials. Both this dryer and the above mentioned dryer works on the principle of greenhouse effect. The only difference from the previous dryer (Fig.1) is that the biomass backup heater coupled to this dryer. The biomass heater can be ignited by any type of fuel such as coconut fronts, coconut shell and coconut husk. The biomass heater should be loaded for every one hour interval so as to provide sufficient heat inside the dryer through the flue gas pipe that runs through the dryer. The flue gas pipes are there to radiate heat to the dryer thereby providing heat to it for the effective drying even at night time and rainy days.

V. INSTRUMENTATION

Figures Calibrated thermocouples (8 numbers, PT 100, uncertainty ±1%) were fixed at different locations inside drier to measure air temperature. Humidity sensors (4 numbers, uncertainty ±1%) were placed at different locations inside drier for measuring air humidity. Ambient humidity was calculated based on measured values of wet and dry bulb temperatures, using two calibrated thermometers, one covered with wet cloth. A solar

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intensity meter (Delta Ohm, Italy; uncertainty, ±10%) was used to measure instantaneous solar radiation. All temperature sensors, humidity sensors and solar intensity meter were connected to a computer through a data logger (Simex, Italy). Air velocity at drier exit was measured by using a vane type thermo-anemometer (Equinox, Germany; uncertainty ± 0.1%) was used for weighing samples.

VI. PRINCIPLE OF SOLAR TUNNEL GREENHOUSE DRYER WITH AND WITHOUT BIOMASS HEATER

The solar radiation is transmitted into the drying chamber by the UV stabilized polyethylene film which provides the greenhouse effect. This film allows all the outside solar radiations to pass into the drying chamber and prevent the re radiation from the drying chamber to the outside and there by helps to accumulating the heat inside the drying chamber. Therefore, the temperature inside the drier is always more than the ambient temperature. This will helps to remove the moisture content of the product placed inside the dryer and therefore it gets dried

VII. EXPERIMENTAL PROCEDURE

Experiments were conducted during 23-25th & 27-29th of May, 2014 for the driers placed at Negamam and Nallampalli village of Pollachi, Tamil Nadu (India) respectively. Fresh and good quality grapes were considered as the drying product for this experiment. Initial moisture content was calculated by taking 10 different samples from different locations inside the drier. Fresh grapes were loaded over trays (having 90% porosity) of drier unit. Then, the exhaust vents were opened to exhaust initial high humid air. Solar intensity, ambient temperature, dryer temperature and air velocity were measured every 1 h interval till end of drying. During night time (i.e.) in the absence of sun (after 5 PM), to maintain the temperature inside the dryer, biomass such as coconut fronts, coconut husk, coconut shell etc. have been added as a fuel to give heat to solar tunnel dryer. Mass of the fuel added was about 7.5kg/hr and was added for every one hour interval from 5PM (previous day) to 8AM (next day).

VIII. DATA ANALYSIS

A. Determination of Moisture Content

About 10 g samples were chopped from randomly selected five red chillies and kept in a convective electrical oven, maintained at 105 ± 1 ^{O}C for 5 hrs. Initial *(m_i)* and final mass *(m_f)* at time (t) of samples were recorded using electronic balance and repeated every 1 h interval till the end of drying. Moisture content on wet basis (M_{wb}) is defined as

$M_{wb} = (m_i - m_f) / m_i$

where, m_i and m_f are initial and final weight of samples respectively.

IX. RESULTS AND DISCUSSIONS

B. Variation of temperature with time

The fig.3 shows the variation of ambient temperature and dryer temperature with and without biomass backup heater over time during the experimental period for the drying of grapes in Pollachi region. During the first 24 hours of the experiment (first day) in the dryer that is coupled with the biomass heater, the temperature inside the dryer varied between 38°C and 64°C with a peak value of 64°C at around 1.00 p.m. , the ambient temperature varied between 22°C and 40°C with a peak value of 40°C at around 1.00 p.m. whereas for the dryer without the biomass heater, the temperature inside the dryer varied between 40°C and 62°C with a peak value of 62°C at around 1.00p.m., the ambient temperature varied between 29°C and 37°C with a peak value of 37°C at around 1.00 p.m. During the next 24 hours of the experiment (second day) in the dyer that is coupled with the biomass heater, the temperature inside the dryer varied between 39°C and 62°C with a peak value of 62°C at around 1.00 p.m. , the ambient temperature varied between 22°C and 39°C with a peak value of 39°C at around 1.00 p.m. whereas for the dryer without the biomass heater, the temperature inside the dryer varied between 42°C and 62°C with a peak value of 62°C at around 1.00p.m., the ambient temperature varied between 30°C and 39°C with a peak value of 39°C at around 1.00 p.m.

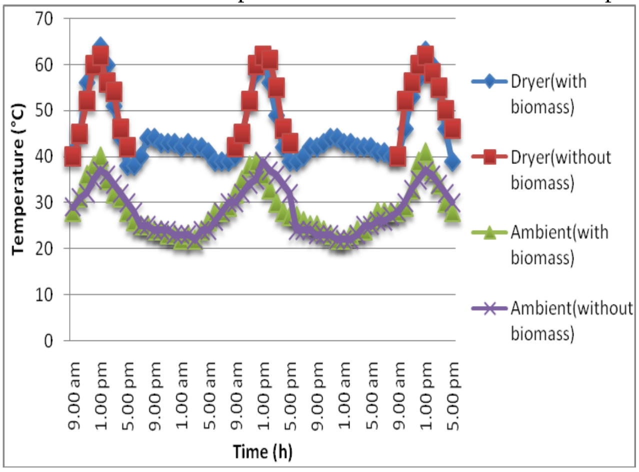

Fig.3 Variation of temperature with time

During the last 24 hours of the experiment (third day) in the dryer that is coupled with the biomass heater, the temperature inside the dryer varied between 39°C and 63°C with a peak value of 63°C at around 1.00 p.m. , the ambient temperature varied between 28°C and 41°C with a peak value of 41°C at around 1.00 p.m. whereas for the dryer without the biomass heater, the temperature inside the dryer varied between 40°C and 62°C with a peak value of 62°C at around 1.00p.m., the ambient temperature varied between 28°C and 37°C with a peak value of 37°C at around 1.00 p.m. It is clear from the figure that the temperature inside the dryer that is coupled with the biomass heater was 3°C to 5°C more than the temperature inside the dryer without the biomass heater in all the three days of the experimental period. It is evident that the grapes dried at an earlier time in the dryer coupled with the biomass heater than the dryer that is without the biomass heater which is due to the high temperature prevailed all the time inside the former dryer as a result of biomass heater. It also reveals that the there was a steady increase in temperature in the dryer that is coupled with the biomass heater even at low sunshine period and night time which is due to the effect of biomass heater coupled to the dryer. This steady increase in temperature is responsible for

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the drying of grapes at an earlier time than the dryer without the biomass heater and the open sun drying method.

C. Variation of relative humidity with time

The fig.4 shows the variation of relative humidity of the dryer with and without biomass heater over time during the experimental period. During the first 24 hours of the experiment (first day) in the dryer that is coupled with biomass heater, the relative humidity of the dryer varied between 27% and 45%, the ambient relative humidity varied between 49% and 86% whereas for the dryer without the biomass heater, the relative humidity varied between 29% and 50%, the ambient relative humidity varied between 40% and 72%.

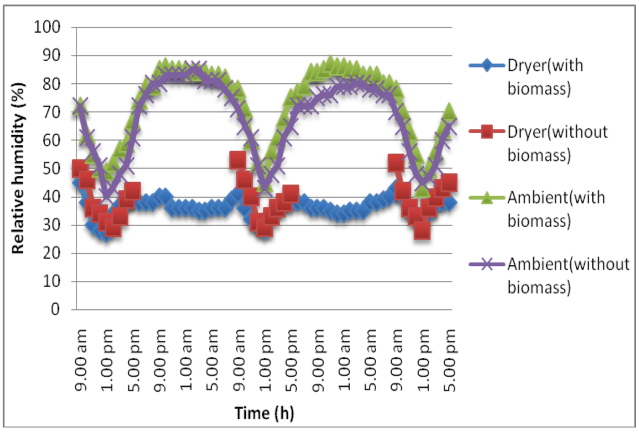

Fig. 4 Variation of relative humidity with time

During the next 24 hours of the experiment (second day) in the dryer that is coupled with biomass heater, the relative humidity of the dryer varied between 28% and 41%, the ambient relative humidity varied between 45% and 86% whereas for the dryer without the biomass heater, the relative humidity varied between 29% and 53%, the ambient relative humidity varied between 43% and 71%. During the last 24 hours of the experiment (third day) in the dryer that is coupled with the biomass heater, the relative humidity of the dryer varied between 30% and 43%, the ambient relative humidity varied between 43% and 78% whereas for the dryer without the biomass heater, the relative humidity varied between 28% and 52%, the ambient relative humidity varied between 45% and 70%. From the fig.4, it is clear that the relative humidity of the dryer that is coupled with the biomass heater was less when compared with the relative humidity of the dryer without the biomass heater which is primarily due to the effect of biomass heater coupled to the dryer. This low relative humidity is responsible for the reducing drying time of the grapes inside the dryer that is coupled with the biomass heater and also for the prevention of fungal and bacterial infections over the products (grapes).

D. Variation of velocity with time

The fig.5 shows the variations of ambient velocity and the velocities of the dryer with biomass and without biomass heater over time during the experimental period. During the first 24 hours of the experiment (first day) in the dryer that is coupled with the biomass heater, the velocity of air inside the dryer varied between 1.1 m/s and 2.8 m/s and the ambient air velocity varied between 1.5 m/s and 3.3 m/s whereas for the dryer without the biomass heater, air velocity varied between 0.8 m/s and 1.3 m/s and the ambient air velocity varied between 1.6 m/s and 2.8 m/s. During the next 24 hours of the experiment (second day) in the dryer that is coupled with the biomass heater, the velocity of air inside the dryer varied between 0.1 m/s and 2.3 m/s and the ambient air velocity varied between 0.8 m/s and 3.2 m/s whereas for the dryer without the biomass heater, air velocity varied between 1 m/s and 2.1 m/s and the ambient air velocity varied between 1.9 m/s and 3.2 m/s. During the last 24 hours of the experiment (third day) in the dryer that is coupled with the biomass heater, the velocity of air inside the dryer varied between 1.1 m/s and 2.5 m/s and the ambient air velocity varied between 1.3 m/s and 2.8 m/s whereas for the dryer without the biomass heater, air velocity varied between 1 m/s and 1.9 m/s and the ambient air velocity varied between 2 m/s and 2.9 m/s. It can be clearly seen that the air velocity inside the dryer that is coupled with the biomass heater was more than the air velocity inside the dryer that is without the biomass heater which is due to the high temperature prevailed all the time inside the dryer (with biomass heater) even during the night time. This increase in air velocity makes the products (grapes) to dry at an earlier time than the open sun drying method and the dryer without the biomass heater.

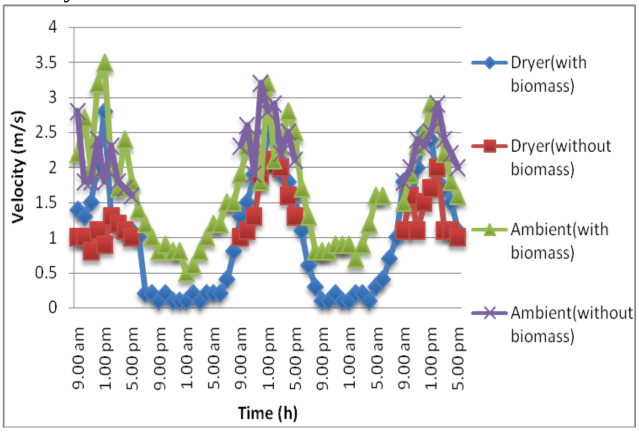

Fig. 5 Variation of velocity with time

E. Variation of sheet temperature with time

The fig.6 shows the variations of sheet temperature inside and outside the dryer (with and without biomass heater) over time during the experimental period. During the first 24 hours of the experiment (first day), the sheet temperature inside the dryer varied from 40°C and 65°C, the sheet temperature outside the dryer varied from 22°C and 40°C whereas for the dryer without the biomass heater, the sheet temperature inside the dryer varied from 41°C and 62°C, the sheet temperature outside the dryer varied from 30°C and 37°C. During the next 24 hours of the experiment (second day), the sheet temperature inside the dryer varied from 40°C and 63°C, the sheet temperature outside the dryer varied from 23°C and 39°C whereas for the dryer without the biomass heater, the sheet temperature inside the dryer varied from 42°C and 62°C, the sheet temperature outside the dryer varied from 32°C and 39°C. During the last 24 hours of the experiment (third day), the sheet temperature inside the dryer varied from 39°C and 63°C, the sheet temperature outside the dryer varied from 28°C and 40°C whereas for the dryer without the biomass heater, the sheet temperature inside the dryer varied from 41°C and 61°C, the sheet temperature outside the dryer varied from 29°C and 38°C. It is evident that the sheet temperature inside the dryer that is coupled with the biomass heater was more than the sheet temperature inside the dryer without the biomass heater which is due to the effect of biomass heater coupled to the dryer. This high temperature inside the dryer accelerated the moisture removal rate thereby reducing drying time of the grapes in the dryer with biomass heater. Also, this high temperature prevented the quality degradation factors of the grapes which claim to produce grapes of good qualities.

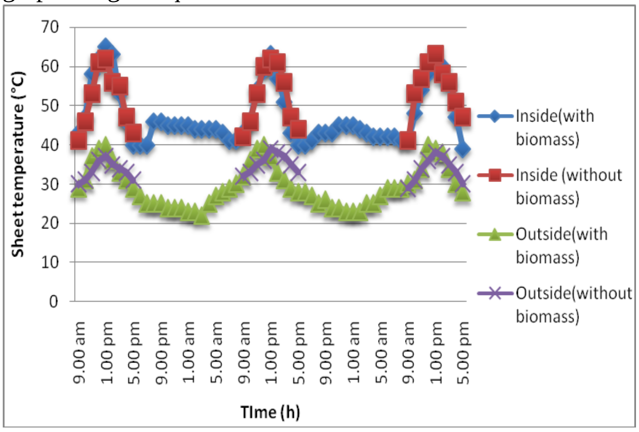

Fig. 6 Variation of sheet temperature with time

F. Variation of floor temperature with time

The fig.7 shows the variation of floor temperature of the dryer with and without the biomass heater over time during the experimental period. During the first 24 hours of the experiment (first day) in the dryer that is coupled with the biomass heater, the temperature of the floor inside the dryer varied from 42°C and 66°C whereas for the dryer without the biomass heater, the temperature of the floor inside the dryer varied from 42°C and 63°C.

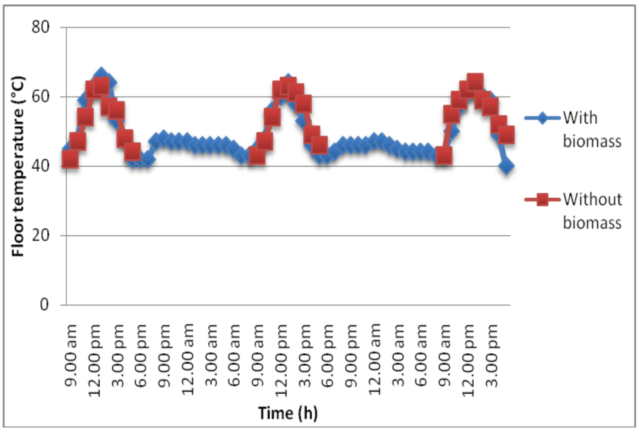

Fig. 7 Variation of floor temperature with time

During the next 24 hours of the experiment (second day) in the dryer that is coupled with the biomass heater, the temperature of the floor inside the dryer varied from 43°C and 64°C whereas for the dryer without the biomass heater, the temperature of the floor inside the dryer varied from 43°C and 63°C. During the last 24 hours of the experiment (third day) in the dryer that is coupled with the biomass heater, the temperature of the floor inside the dryer varied from 40°C and 63°C whereas for the dryer without the biomass heater, the temperature of the floor inside the dryer varied from 43°C and 64°C. From the figure, it is clear that the floor temperature of the dryer that is coupled with the biomass heater is more than the floor temperature of the dryer without the biomass heater which is primarily due to the effect of biomass heater that steadily increased the temperature inside the dryer even after the fall in sunshine (after 5PM). Thus, this is also the reason for the reduced drying time inside the dryer (with biomass heater) than that of the open sun drying method and the dryer without biomass heater.

G. Variation of product temperature with time

The fig.8 shows the variation of product temperature inside and outside the dryer (with biomass and biomass heater) over time during the experimental period. During the first 24 hours of the experiment (first day), the product temperature inside the dryer varied from 44°C and 67°C, the product temperature outside the dryer varied from 23°C and 40°C whereas for the dryer without the biomass heater, the product temperature inside the dryer varied from 44°C and 64°C, the product temperature outside the dryer varied from 23°C and 40°C. During the next 24 hours of the experiment (second day), the product temperature inside the dryer varied from 45°C and 65°C, the product temperature outside the dryer varied from 23°C and 39°C whereas for the dryer without the biomass heater, the product temperature inside the dryer varied from 46°C and 65°C, the product temperature outside the dryer varied from 32°C and 39°C.

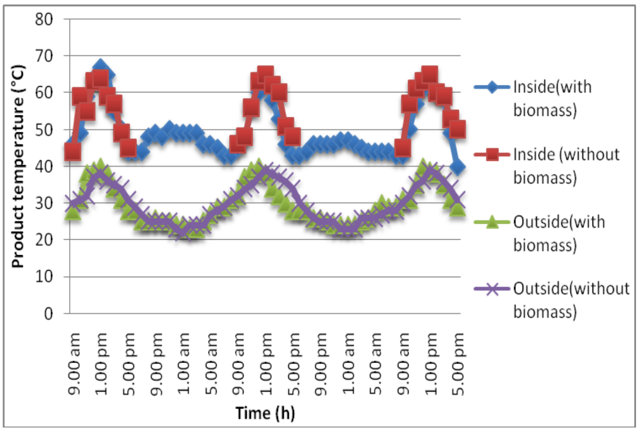

Fig. 8 Variation of product temperature with time

During the last 24 hours of the experiment (third day), the product temperature inside the dryer varied from 42°C and 64°C, the product temperature outside the dryer varied from 29°C and 40°C whereas for the dryer without the biomass heater, the product temperature inside the dryer varied from 45°C and 65°C, the product temperature outside the dryer varied from 30°C and 39°C. It is evident that the temperature of the product inside the dryer that is coupled with the biomass heater was more than that of the dryer without the biomass heater which is due to the high temperature (that prevailed as a result of biomass heater) inside the dryer (with biomass heater) all throughout the day even in the time where there would be a drop in sunshine. Thus this proves that superior quality products (grapes) can be obtained from the dryer that is coupled with the biomass heater than that of the dryer without biomass heater and the open sun drying method. Also, there are no fungal and bacterial infections over the product (grapes) which is due to the high temperature that is constantly maintained inside the dryer coupled with the biomass heater even at night time.

H. Variation of moisture content with time

The fig.9 shows the variation of moisture content of the grapes dried under the open sun drying method and inside the dryer with biomass and without biomass heater over time during the experimental period. During the first 24 hours of the experiment (first day) in the dryer that is coupled with the biomass heater, the moisture content of the grapes inside the dryer reduced from 80% to 26.39% and the moisture content of the open sun dried grapes reduced from 80% to 64.49% whereas for the dryer without biomass heater, the moisture content of the grapes inside the dryer reduced from 80% to 57.5% and the moisture content of the open sun dried grapes reduced from 80% to 64.32%. During the next 24 hours of the experiment (second day) in the dryer with the biomass heater, the moisture content of the grapes inside the dryer reduced from 26.39% to 10.08% and the moisture content of the open sun dried grapes reduced from 64.49% to 49.55% whereas for the dryer without biomass heater, the moisture content of the grapes inside the dryer reduced from 57.5% to 29.5% and the moisture content of the open sun dried grapes reduced from 64.32% to 52.2%. By the end of the second day, the moisture content of the grapes in the dryer that is coupled with the biomass heater, is reduced to 10.08% in 31 hours which is the maximum rate of moisture removal from grapes for the process of safe storage to avoid spoilage; whereas the open sun drying method took 148 hours for the removal of moisture content from the grapes to the same level.

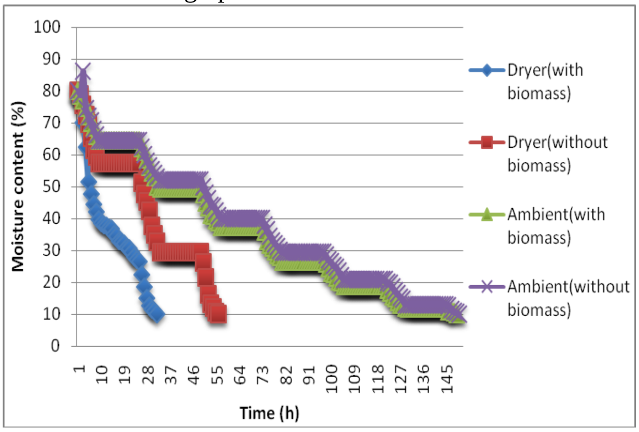

Fig. 9 Variation of moisture content with time

During the third day of the experiment, the moisture content of the grapes inside the dryer without the biomass heater reduced from 29.5% to 10% and the moisture content of the open sun dried grapes reduced from 52.2% to 40%. By the end of third day, the moisture content of the grapes inside the dryer without the biomass heater, is reduced to 10% in 55 hours, which is the maximum rate of moisture content that can be removed from the grapes whereas the open sun drying method took 149 hours for the reduction of moisture content of the grapes to the same level. It can be seen that the dryer coupled with the biomass heater took 30 hours for reducing the moisture content of the grapes from 80% to 10.08% whereas the dryer without the biomass heater took 55 hours for reducing the moisture content to the same level. This shows that the dryer coupled with the biomass heater is more efficient in drying the products at a quicker time which is mainly due to the effect of biomass heater that steadily maintained the high temperature and low relative humidity inside the dryer even at night time. This higher rate of moisture removal from the grapes in the dryer (with biomass heater) is the prime reason for the reduced drying time in the dryer than that of the dryer without biomass heater and the open sun drying method and also it helps in eliminating the fungal and bacterial infections thereby producing superior quality grapes in the solar tunnel greenhouse dryer coupled with the biomass heater.

X. CONCLUSION

Experiments were conducted in a natural convection solar tunnel greenhouse dryer coupled with biomass heater situated at Nallampalli village of Pollachi, Tamil Nadu (India) and also in a natural convection solar tunnel greenhouse dryer without biomass heater situated at Negamam village of Pollachi, Tamil Nadu (India) during the month of May, 2014 in order to experimentally study and compare the drying characteristics of grapes in those dryers and in the open sun drying method and also to find out optimum drying method for the drying of grapes. Three experimental runs with 40kgs of grapes were carried out in those respective dryers for drying. The mass of fuel added (after 5PM) to the biomass heater was about 7.5kg/hr. The biomass was ignited after 5PM for every one hour with fuel such as firewood, coconut shell, coconut husk and coconut fronts.

Fig. 10 Comparison of grapes dried in open sun drying method and in the solar tunnel greenhouse dryer without the biomass heater

The Fig.10 shows the comparison of grapes dried in the OSD method and in the solar tunnel dryer without the biomass heater respectively. From the experiment, it was found that the grapes which has the initial moisture content of 80% (w.b.) was reduced to 10.08% (w.b.) over a time period of 31 hours in the solar tunnel greenhouse dryer coupled with biomass heater whereas the dryer without the biomass heater took 55 hours for reducing the moisture content of the grapes to the same level.

Fig. 11 Comparison of grapes dried in open sun drying method and in the solar tunnel greenhouse dryer with biomass heater

The Fig.11 shows the comparison of grapes dried in the OSD method and in the solar tunnel dryer with biomass heater respectively. Also, the open sun drying method took 149 hours for reducing the moisture content of the grapes from 80% (w.b.) to 10% (w.b.). It was found that there was steady increase in temperature inside the dryer that is coupled with the biomass heater all the time irrespective of drop in sunshine which is basically due to the effect of biomass heater and the green house effect that supplied sufficient heat to the dryer during night time (after 5PM). This high temperature, low relative humidity and the greenhouse effect in the dryer (with biomass heater), further accelerated the rate of moisture removal from the grapes which leads to the reduced drying time than that of the dryer without biomass heater and the open sun drying method. The drying time of grapes in the solar tunnel greenhouse dryer coupled with the biomass heater is less than the drying time of the grapes in the dryer without biomass heater and the open sun drying method which is primarily due to the effect of biomass heater coupled to the dryer. Also, there is no quality degradation of products (grapes) in the solar tunnel greenhouse dryer that is coupled with the biomass heater since there is no effect of fungal and bacterial infections, & damage by rodents and birds that is made possible by the higher rate of moisture removal from the grapes and also by high temperature and low relative humidity inside the dryer all the time. Thus, solar tunnel greenhouse dryer coupled with the biomass heater proves to be more efficient in drying of grapes than that of the dryer without the biomass heater and the open sun drying method.

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