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Optimization and Comparison Studies of 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 (existing dryer) was designed and developed in Negamam region of Pollachi, Tamil Nadu (India) for the comparison and optimization of the existing solar tunnel greenhouse dryer by conducting a drying test in both the dryers with coconut as the drying product during the month of March, 2014. About 5000 coconuts were loaded into those two respective 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. The drying parameters (product quality and drying time) were also taken into account for the optimization of the existing dryer. The solar tunnel dryer coupled with the biomass heater dried the coconuts which has an initial moisture content of 53.84% to a final moisture content of 7.003% over a time period of 44 hours whereas the solar tunnel greenhouse dryer without the biomass heater took 56 hours for reducing the moisture content to the same level. The drying time of the coconuts in the solar tunnel greenhouse dryer coupled with the biomass heater was less than that of the solar tunnel greenhouse dryer without the biomass heater which is due to the effect of biomass heater that supplied sufficient heat to the dryer so that the temperature inside the dryer would be increasing steadily even at night time. Also the quality of the coconuts obtained from the solar tunnel greenhouse dryer coupled with biomass heater was found to be superior to that of the coconuts 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 backup heater, coconuts, drying time, moisture content, open sun drying, product quality, relative humidity, solar tunnel greenhouse dryer, temperature.

I. INTRODUCTION

The unpredictable rise and frequent scarcity of fossil fuel accelerated the continuous search for an alternative power source. Solar is one of the renewable and sustainable sources of power that attracted a large community of researchers from all over the world. Drying of fruits and vegetables is one of the oldest methods of food preservation and it is being practiced still nowadays.

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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. India ranks third largest coconut producing country (area, 15.5%, coconut production, 21%) in the world. It annually produces 14.81 billion nuts from an area of 1.93 million ha1. Copra is richest source of oil (70%). Moisture content (53.84%, wet basis) in fresh coconuts is required to be reduced to 7% by drying to concentrate oil content. Copra, the dried edible part of coconut is produced after drying of coconut. To obtain oil from copra, it has to be dried effectively. In developing countries like India, the traditional method of open sun drying is practiced where the coconuts will be cut into two halves and placed in the floor of the drying yard (facing the sun) which may be made of cement, marbles and even soil. In this traditional method, in order to obtain an optimum price for the production of oil from coconuts, farmers are following certain pretreatment process of coconuts. In the open sun drying method, there will be several factors which affects the quality of the coconuts such as damage by birds and animals, contamination by insects, fungal and bacterial infections etc. Thus this leads to the production of poor quality coconuts thereby affecting the market price of the coconuts which in turn affects the farmers. The farmers cannot sell their products if the quality is low. To overcome these factors, farmers are following the practice of sulphur fumigation where the sulphur will be sprayed in form of vapour over the coconuts. This method helps the farmers to earn profit as it attracts the traders to a greater extent since the coconuts will be free from fungal and bacterial infections. Though this sulphur fumigation prevents the quality degradation of coconuts to an extent, it has an adverse effect on the human health. When oil is extracted from these types of coconuts, the resulting oil will affects the consumers in several ways such as vomiting and illness when consumed through food, hair loss when applied, change in the texture of skin when applied, etc. Moreover, this practice of open sun drying normally took 5-7 days for reducing the moisture content of coconuts from 53.84% to 7% to concentrate oil content. This seems to be a time consuming process and an inefficient one. To outdate this traditional open sun dying, a natural convection solar tunnel greenhouse dryer was designed and developed in Negamam region of Pollachi, Tamil Nadu (India).

This dryer 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. Various studies have been reported for solar tunnel greenhouse crop drying [1]-[4]. Moreover, the solar tunnel greenhouse dryer overcomes the effects of 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. Moreover, the quality of coconuts obtained from the solar tunnel greenhouse dryer was found to be superior to that of open sun dried coconuts. 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 coconuts 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 March, 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)

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. Three exhaust vents with adjustable butterfly valves were provided at roof top. 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

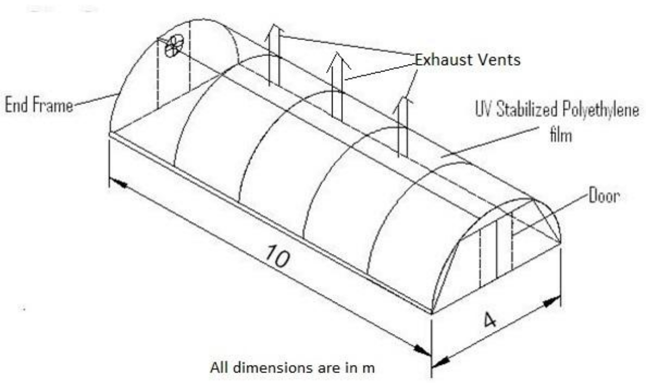

Fig. 1 Solar Tunnel Greenhouse Dryer

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

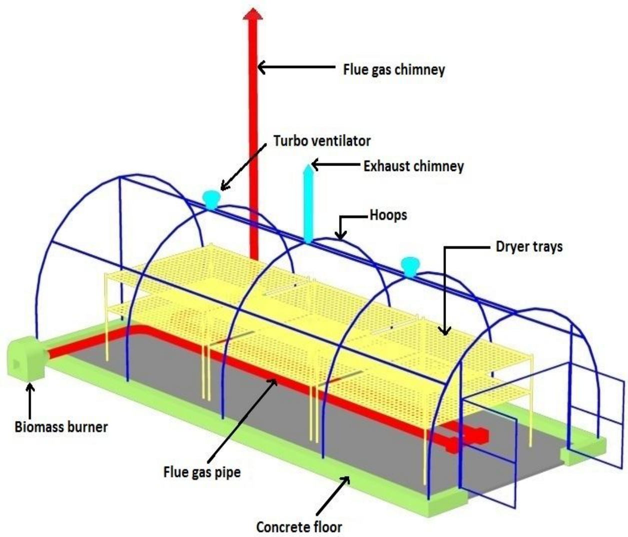

Fig. 2 Solar Tunnel Greenhouse Dryer Coupled with Biomass Backup Heater

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 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 15-17th & 18-20th of March, 2014 for the driers placed at Negamam and Nallampalli village of Pollachi, Tamil Nadu (India) respectively. Matured and good quality coconuts were cut into several pieces. Initial moisture content was calculated by taking 10 different samples from different locations inside the drier. Broken coconuts along with shell 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 cups 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

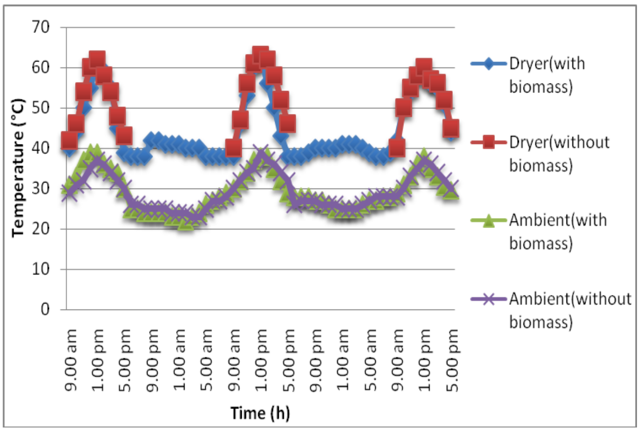

Fig. 3 Variation of Temperature with Time

The fig.3 shows the variation of ambient temperature and dryer temperature with and without biomass backup heater over time during the experimental period. During the first 24 hours of the experiment (first day) in the dryer coupled with biomass heater, the temperature inside the dryer varied between 38°C and 61°C with a peak value of 61°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 23°C and 36°C with a peak value of 36°C at around 1.00 p.m. During the next 24 hours of the experiment (second day) in the dyer coupled with biomass heater, the temperature inside the dryer varied between 38°C and 62°C with a peak value of 62°C at around 1.00 p.m. , the ambient temperature varied between 25°C and 38°C with a peak value of 38°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 63°C with a peak value of 63°C at around 1.00p.m., the ambient temperature varied between 25°C and 39°C with a peak value of 39°C at around 1.00 p.m.

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During the last 24 hours of the experiment (third day) in the dryer coupled with biomass heater, the temperature inside the dryer varied between 42°C and 60°C with a peak value of 60°C at around 1.00 p.m. , the ambient temperature varied between 29°C and 38°C with a peak value of 38°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 60°C with a peak value of 60°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 evident from the figure that the temperature inside the dryer which is coupled with the biomass heater was 5°C to 7°C more than the temperature inside the dryer without the biomass heater in all the three days of the experiment. It also shows that that the temperature inside the dryer which is coupled with the biomass heater was increasing steadily even at the absence of solar radiation (after 5PM) which is due to the effect of biomass backup heater. This steady increase in temperature dried the coconuts at a much earlier time than the dryer without the biomass heater and the open sun drying method.

C. Variation of Relative Humidity with Time

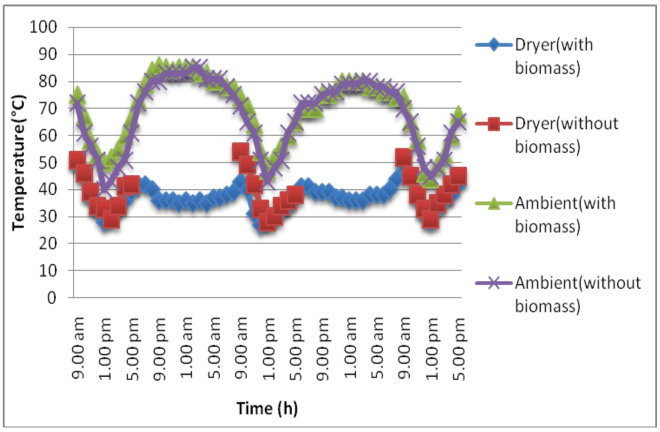

Fig. 4 Variation of Relative Humidity with Time

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 28% and 49%, the ambient relative humidity varied between 50% and 86% whereas for the dryer without the biomass heater, the relative humidity varied between 29% and 51%, the ambient relative humidity varied between 40% and 85%. During the next 24 hours of the experiment (second day) in the dryer inside the dryer that is coupled with biomass heater, the relative humidity of the dryer varied between 27% and 44%, the ambient relative humidity varied between 47% and 80% whereas for the dryer without the biomass heater, the relative humidity varied between 28% and 54%, the ambient relative humidity varied between 43% and 80%. 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 27% and 49%, the ambient relative humidity varied between 44% and 74% 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%. It can be seen that relative humidity in 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 due to the steady increase in temperature inside the dryer (with biomass heater) even when there was a fall in sunshine (after 5PM). This clearly reveals that the dryer coupled with the biomass heater would be more efficient in drying the products at an earlier time than the dryer without the biomass heater. By using this dryer (with biomass heater), the drying can be done at a very quicker time than the open sun drying with superior quality.

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 0.1 m/s and 2.5 m/s and the ambient air velocity varied between 0.5 m/s and 3.5 m/s whereas for the dryer without the biomass heater, air velocity varied between 1 m/s and 1.5 m/s and the ambient air velocity varied between 1.6 m/s and 2.8 m/s.

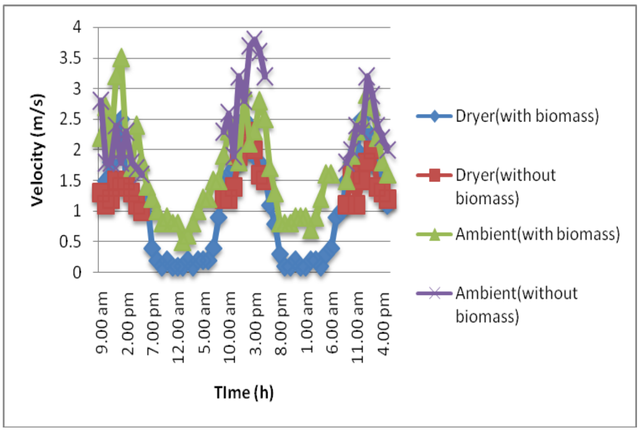

Fig. 5 Variation of Air Velocity with Time

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 2.7 m/s and the ambient air velocity varied between 0.7 m/s and 3 m/s whereas for the dryer without the biomass heater, air velocity varied between 1.2 m/s and 2.3 m/s and the ambient air velocity varied between 1.9 m/s and 3.8 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 1.5 m/s and 2.9 m/s whereas for the dryer without the biomass heater, air velocity varied between 1.1 m/s and 2 m/s and the ambient air velocity varied between 1.8 m/s and 3.2 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 (coconuts) to dry at an earlier time than the open sun drying method and the dryer without the biomass heater.

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 66°C, the sheet temperature outside the dryer varied from 24°C and 38°C whereas for the dryer without the biomass heater, the sheet temperature inside the dryer varied from 41°C and 63°C, the sheet temperature outside the dryer varied from 30°C and 38°C. During the next 24 hours of the experiment (second day), the sheet temperature inside the dryer varied from 40°C and 67°C, the sheet temperature outside the dryer varied from 26°C and 41°C whereas for the dryer without the biomass heater, the sheet temperature inside the dryer varied from 39°C and 64°C, the sheet temperature outside the dryer varied from 31°C and 41°C. During the last 24 hours of the experiment (third day), the sheet temperature inside the dryer varied from 44°C and 65°C, the sheet temperature outside the dryer varied from 29°C and 39°C whereas for the dryer without the biomass heater, the sheet temperature inside the dryer varied from 38°C and 61°C, the sheet temperature outside the dryer varied from 31°C and 40°C.

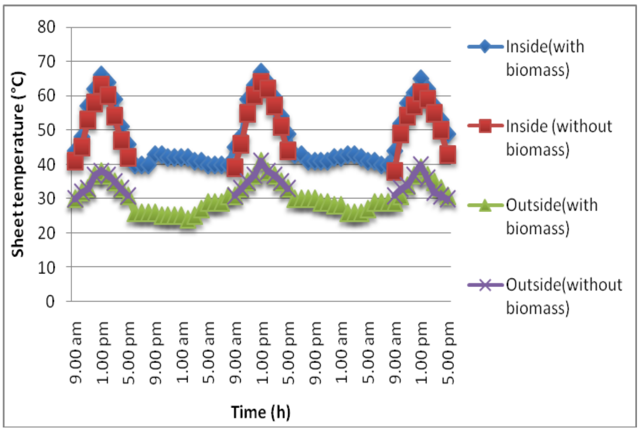

Fig. 6 Variation of Sheet Temperature with Time

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 which makes the dryer (with biomass heater) to dry the products (coconuts) at an earlier time than the dryer without the biomass heater.

F. Variation of Floor Temperature with Time

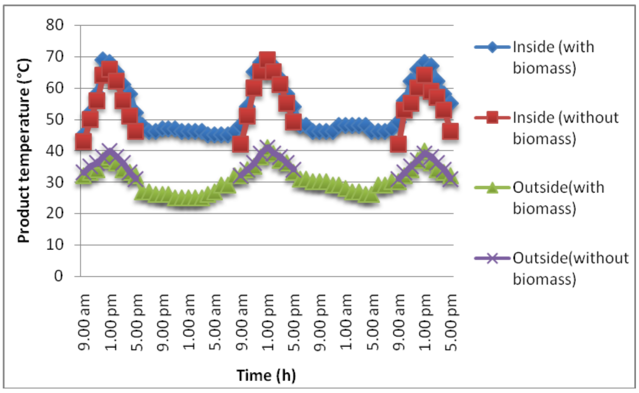

Fig. 7 Variation of Floor Temperature with Time

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 68°C whereas for the dryer without the biomass heater, the temperature of the floor inside the dryer varied from 43°C and 67°C. 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 44°C and 69°C whereas for the dryer without the biomass heater, the temperature of the floor inside the dryer varied from 41°C and 67°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 46°C and 68°C whereas for the dryer without the biomass heater, the temperature of the floor inside the dryer varied from 41°C and 65°C. From the fig.7, 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).

G. Variation of product temperature with time

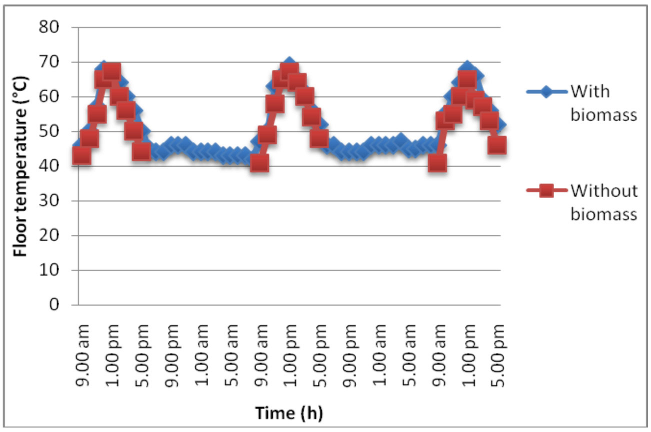

Fig. 8 Variation of Product Temperature with Time

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 45°C and 65°C, the product temperature outside the dryer varied from 25°C and 38°C whereas for the dryer without the biomass heater, the product temperature inside the dryer varied from 43°C and 66°C, the product temperature outside the dryer varied from 31°C and 40°C. During the next 24 hours of the experiment (second day), the product temperature inside the dryer varied from 46°C and 69°C, the product temperature outside the dryer varied from 26°C and 41°C whereas for the dryer without the biomass heater, the product temperature inside the dryer varied from 42°C and 69°C, the product temperature outside the dryer varied from 32°C and 41°C. During the last 24 hours of the experiment (third day), the product temperature inside the dryer varied from 49°C and 68°C, the product temperature outside the dryer varied from 31°C and 40°C whereas for the dryer without the biomass heater, the product temperature inside the dryer varied from 42°C and 64°C, the product temperature outside the dryer varied from 31°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 reveals the fact that the higher temperature prevailed in the dryer (with biomass heater) even after the fall in sunshine (after 5PM).

H. Variation of Moisture Content with Time

The fig.9 shows the variation of moisture content of the coconuts 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 coconuts inside the dryer reduced from 53.84% to 25.56% and the moisture content of the open sun dried coconuts reduced from 53.84% to 46.32% whereas for the dryer without biomass heater, the moisture content of the coconuts inside the dryer reduced from 53.84% to 33.21% and the moisture content of the open sun dried coconuts reduced from 53.84% to 45.5%.

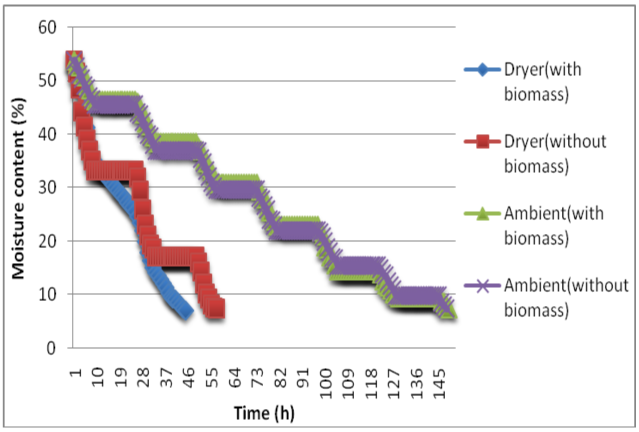

Fig. 9 Variation of Moisture Content with Time

During the next 24 hours of the experiment (second day) in the dryer that is coupled with the biomass heater, the moisture content of the coconuts inside the dryer reduced from 25.56% to 7.003% and the moisture content of the open sun dried coconuts reduced from 46.32% to 38.46% whereas for the dryer without biomass heater, the moisture content of the coconuts inside the dryer reduced from 33.21% to 17.16% and the moisture content of the open sun dried coconuts reduced from 45.5% to 37%. By the end of the second day, the moisture content of the coconuts inside the dryer that is coupled with the biomass heater is reduced to 7.003% in just 44 hours, which is the maximum rate of moisture content that can be removed from the coconuts for the production of oil whereas the open sun drying method took 148 hours for the reduction of moisture content of the coconuts to the same level. During the third day, the moisture content of the coconuts inside the dryer without the biomass heater reduced from 17.16% to 7.4% and the moisture content of the open sun dried coconuts reduced from 38.46% to 30.82%. By the mid of third day, the moisture content of the coconuts inside the dryer without the biomass heater reduced to 7.4% which is the maximum rate of moisture content that can be removed from coconuts for the oil production whereas open sun drying method took 147 hours for the reduction of moisture content of the coconuts to the same level. It can be seen that the dryer coupled with the biomass heater took 44 hours for reducing the moisture content of the coconuts from 53.84% to 7.003% whereas the dryer without the biomass heater took 56 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 whichis 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.

X. CONCLUSION

Experiments were conducted in a natural convection solar tunnel greenhouse dryer coupled with biomass heater (Fig.10) situated at Nallampalli village of Pollachi, Tamil Nadu (India) and also in a natural convection solar tunnel greenhouse dryer without biomass heater (Fig.11) situated at Negamam village of Pollachi, Tamil Nadu (India) during the month of March, 2014 in order to compare and optimize the existing solar tunnel greenhouse dryer. Threeexperimental trails of 5000 coconuts 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 coconuts which has the initial moisture content of 53.84% was reduced to 7.003% over a time period of just 44 hours in the solar tunnel greenhouse dryer coupled with biomass heater whereas the dryer without the biomass heater took 56 hours for reducing the moisture content of the coconuts to the same level. Also, the open sun drying method took 148 hours for reducing the moisture content of the coconuts from 53.84% to 7.4%.

Fig. 10 Drying of Coconuts in a Solar Tunnel Greenhouse Dryer Coupled with Biomass Heater

Fig. 11 Drying of Coconuts in a Solar Tunnel Dryer without Biomass Heater

Fig. 12 Comparison of Coconuts Dried in Solar Tunnel Dryer without Biomass Heater and with Biomass Heater

The reduced drying time in the solar tunnel greenhouse dryer that is coupled with the biomass heater is due to the high temperature and low relative humidity prevailed all the time inside the dyer even when there was a fall in sunshine (after 5PM). This high temperature and low relative humidity of the dryer (with biomass heater) is due to the effect of biomass heater and the greenhouse effect which as a whole dried the coconuts at an earlier time than the dryer without biomass heater and the open sun drying method. The drying time of coconuts in the solar tunnel greenhouse dryer coupled with the biomass heater is less than the drying time of the coconuts 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. The fig.12 shows the comparison of coconuts dried in solar tunnel dryer without biomass heater and with biomass heater. Also, the quality of coconuts obtained from the dyer coupled with biomass heater was found to be of superior quality than that of the coconuts obtained from the dryer without the biomass heater which is due to the high temperature prevailed all the time irrespective of the fall in sunshine. Thus, the solar tunnel greenhouse dryer coupled with the biomass heater proves to be more efficient in drying coconuts in terms of drying time and product quality.

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REFERENCES

1. D. Jain, G. N. Tiwari, “Effect of greenhouse on crop drying under natural forced convection. II. Thermal modeling and experimental validation, *Energy Conversion and Management*, 2004, (45), pp. 2777–2793.
2. D. Jain, G. N. Tiwari, “Effect of greenhouse on crop drying under natural forced convection. I. Evaluation of convective mass transfer coefficient, *Energy Conversion and Management*, 2004, (45), pp. 765-783.
3. A. Ayensu & V. Asiedu-Boudzie , “Solar drying with convective self-flow and energy storage”, *Solar & Wind Technology*, 1986, (3), pp. 273-279
4. M. Mohanraj and P.Chandrasekar, “Comparison of drying characteristics and quality of copra obtained in a forced convection solar drier and sun drying”, *Journal of Scientific and Industrial Research*, 2008, vol. 67, pp.381-385.
5. M. Condori, R. Echazu, & L. Saravia, “Solar drying of sweet pepper and garlic using the tunnel greenhouse drier”, *Renewable Energy*, 2001, vol. 22, pp. 447-460.
6. D. S. Sogi, U.S. Shivhare, S.K. Garg, & A.S. Bawa, “Water sorption isotherm and drying characteristic of tomato seeds”, *Biosystems Engineering*, 2003, vol. 84, pp. 297-301.
7. C. Tiris, N. Özbalta, M. Tiris, & I. Dinçer, “Experimental testing of a new solar dryer”, *International Journal of Energy Research*, 1994, vol. 18, pp. 483-490.
8. A. Gungor & N. Ozbalta, **“** Design of a greenhouse for solar drying of sultana grapes and experimental investigation on it”, İnternational Conference on Thermal Engineering and Thermogrammetry (THERMO), 18-20 June 2003, Budapest, Hungary.
9. Y. M. Gallali, Y. S. Abujnah, & F. K. Bannani, “Preservation of fruits and vegetables using solar dryer: a comparative study of natural and solar drying, III; chemical analysis and sensory evaluation data of the dried samples (grapes, figs, tomatoes and onions)”, *Renewable Energy*, 2000, vol. 19, pp. 203-212.
10. I. Doymaz, & M. Pala, “ Hot-air drying characteristics of red pepper”, *Journal of Food Engineering*, 2002, vol. 55(4), pp. 331-335.

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