Experimental Studies on Drying Characteristics of Coconuts in a Solar Tunnel Greenhouse Dryer Coupled with Biomass Backup Heater

S. Arun, S. Shankar Balaji, P. Selvan

Abstract*— A natural convection solar tunnel greenhouse dryer coupled with biomass backup heater was designed and developed for studying the drying characteristics of coconuts in Pollachi region of Tamil Nadu. Three trails of loading 5000 coconuts in the dryer were carried out during the month of January, 2014. The biomass backup heater was used after 5PM where there would be no sufficient solar radiation and was loaded with the remains of coconut such as coconut fronts, coconut husk and coconut shells which could be used as a fuel for biomass heater. The drying time and the product quality were the main deciding performance parameters of the dryer which are studied in comparison with the traditional drying method (open sun drying). It was found that the coconuts which has an initial moisture content of 53.84% (w.b.) were dried to final moisture content of 7.003% (w.b.) in the solar tunnel greenhouse dryer for a time period of 44 hours whereas the open sun drying method took 148 hours for the reduction of moisture content of the coconuts to the same level. Also, the superior quality coconuts can be produced from the solar tunnel greenhouse dryer since the dryer is free from contamination, dust & dirt, damage by birds and infections by bacteria and fungus.

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

I. INTRODUCTION

Drying is one of the most used methods for product preservation which has been followed from ancient times. Drying is a major post-harvest processing of the food products. Solar energy can be used as an important and environmental compatible source of renewable energy. The use of solar energy for the effective drying of products reduces the problems arising from generating energy by conventional method. The use of the conventional energy source for the purpose of drying is very expensive and it causes pollution. Traditional sun drying or open sun drying takes place by exposing the product to direct sunlight. Though this method has low operating and capital cost, it requires a skillful persons to work in it. However, the disadvantages are more than the advantages which are contamination, damage by birds, rats or insects, slow or intermittent drying, no protection from rain or windborne dust & dirt. In addition, the direct exposure to sunlight reduces the colour and vitamin content of some fruits and vegetables. Moreover, this open sun drying method requires larger area for drying. India is the 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. In India, the conventional method of open sun drying of coconuts is done by spreading the spilt coconuts on the drying yard that may be made of cement, granite, marbles or even just soil. The spilt coconuts will be facing the sun so that the heat will evaporate the moisture present in the coconuts (Fig.1). But the removal of moisture from the coconuts is a time consuming process and is inefficient. Also, there would be contamination by insects, birds, animals and dust thereby leading to spoilage and degradation of the quality of coconuts. If the drying atmosphere is highly humid, there is an enough possibility of fungal and bacterial infections over the products. In order to avoid those infections, farmers used the process of sulphur fumigation over the coconuts so as to keep the coconuts in a good condition, ready to be sold out to the merchants. But the usage of sulphur will have an adverse effect on the consumer's health.

Fig. 1 Open Sun Drying Method

In order to overcome these practical difficulties of open sun drying, a solar tunnel greenhouse dryer coupled with biomass backup heater was designed, fabricated and constructed in Pollachi region, Tamil Nadu. This dryer basically on the principle of greenhouse effect in

Manuscript Received on October 2014.

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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. In order to achieve a continuous drying even in the absence of sunlight (after 5PM), a biomass backup heater was designed, developed and coupled with the solar tunnel greenhouse dryer. This biomass heater can be used as a backup to provide sufficient heat inside the dryer during the night time and the rainy days where there will be no sunlight. Various investigators have studied the drying behaviour of vegetables and fruits such as sweet pepper and garlic [1], tomato seed [2], grape [3] & [4], pineapple [5], tomato [6], figs and onion [7] and red pepper [8]. The objective of this study is to experimentally study the drying characteristics of coconuts in the solar tunnel greenhouse dryer coupled with biomass backup heater and also to compare the open sun dried coconuts and solar tunnel dried coconuts in terms of quality and drying time.

II. EXPERIMENTAL SECTION

Experiments were carried out under meteorological conditions of Pollachi (latitude, 10.39°N; longitude, 77.03°E) in India during the January month of 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 COUPLED WITH BIOMASS BACKUP HEATER

An STD (Fig.1) as a community model solar tunnel greenhouse dryer coupled with biomass backup heater [4 m (W) x 10 m (L) x 3 m (H) at centre] was designed and constructed at Nallampalli 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.

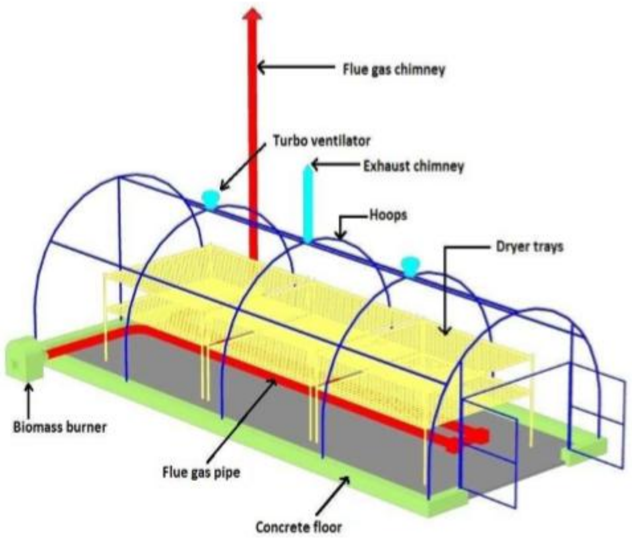

Fig. 2 Solar Tunnel Greenhouse Dryer Coupled with Biomass Backup Heater

Two turbo ventilators are provided at the roof and one exhaust chimney is provided at the centre of the roof top. The biomass backup burner can be ignited with any type of fuel and the fuel used for this experiment was the remains of coconuts such as coconut fronts, coconut husk etc. 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. 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.

V. PRINCIPLE OF SOLAR TUNNEL GREENHOUSE DRYER

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.

VI. EXPERIMENTAL PROCEDURE

Experiment was conducted during 22-24th of January, 2014 for the drier placed at Nallampalli village of Pollachi, Tamil Nadu. 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

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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.

VII. 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°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.

VIII. RESULTS AND DISCUSSIONS

B. Variation of Solar Intensity and Temperature with Time

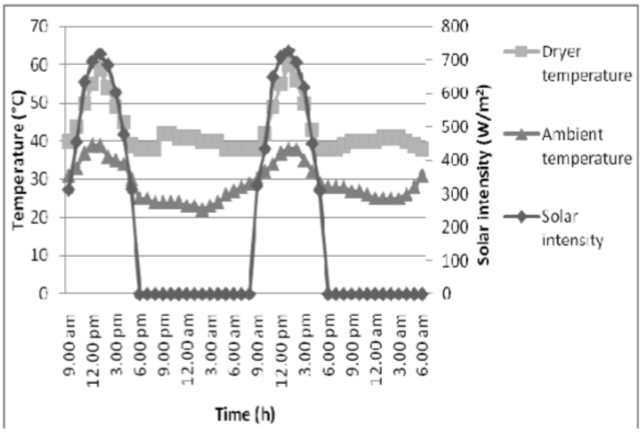

Fig. 3 Variation of Solar Intensity and Temperature with Time

The fig.3 shows the variation of solar intensity, ambient temperature and dryer temperature during the experimental period (22-24th January, 2014). During the first 24 hours of the experiment (first day), the solar intensity varied between 313 W/m^2 and 717 W/m^2, the ambient temperature varied between 22°C and 39°C with a peak value of 39°C at around 1.00 p.m. and the dryer temperature varied between 38°C and 59°C with a peak value of 59°C at around 1.00p.m. During the next 24 hours of the experiment (second day), the solar intensity varied between 310 W/m^2 and 727 W/m^2, the ambient temperature varied between 25°C and 38°C with a peak value of 38°C at around 1.00 p.m. and the dryer temperature varied between 38°C and 60°C with a peak value of 60°C at around 1.00p.m. It is clear from the figure that the dryer temperature was 11°C to 22°C more than the ambient temperature in both the two days of experiment which shows that the temperature inside the dryer was increasing steadily even at the absence of solar radiation (after 5PM) which is due to the biomass backup heater and the greenhouse effect. This steady increase in temperature enabled the solar tunnel greenhouse dryer to dry the coconuts at a much earlier time than the open sun drying method. Also, the drier temperature varied according to the solar intensity during this experimental period. The maximum solar radiation observed was about 727 W/m^2.

C. Variation of Relative Humidity with Time

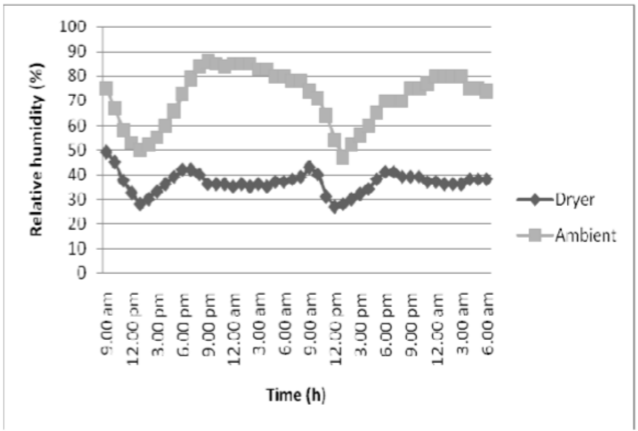

Fig. 4 Variation of Relative Humidity with Time

The fig.4 shows the variation of dryer relative humidity and ambient relative humidity during the experimental period. During the first 24 hours of the experiment (first day), the relative humidity of the dryer varied between 28% and 49% whereas the ambient relative humidity varies between 50% and 86%. During the next 24 hours of the experiment, the relative humidity of the dryer varied between 27% and 41% whereas the ambient relative humidity varied between 47% and 80%. The relative humidity of the dryer was less than that of ambient relative humidity due to the high temperature prevailed all the time inside the dryer even at night time (after 5PM) which is primarily due to the biomass backup heater and also due to the greenhouse effect. Thus, the solar tunnel greenhouse dryer coupled with biomass backup heater helps in drying the products at a very quicker time than the open sun drying method.

D. Variation of Air Velocity with Time

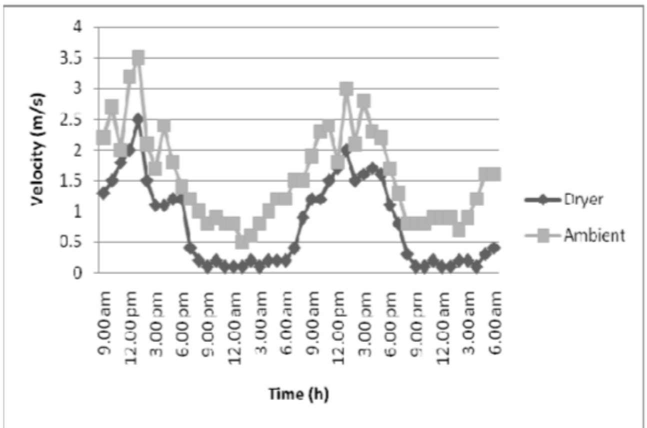

Fig. 5 Variation of Air Velocity with Time

The fig.5 shows the variation of ambient air velocity and dryer air velocity during the

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experimental period. During the first 24 hours of the experiment (first day), the ambient air velocity varied between 0.5 m/s and 3.5 m/s whereas the dryer air velocity varied between 0.1 m/s and 2.5 m/s. During the next 24 hours of the experiment, the ambient air velocity varied between 0.8 m/s and 3 m/s whereas the dryer air velocity varied between 0.1 m/s and 2 m/s. It was evident that the dryer air velocity is lesser than the ambient air velocity due to the buoyancy effect inside the dryer. This is the reason for the lower air velocity and increased drying rate inside the dryer.

E. Variation of Moisture Content with Time

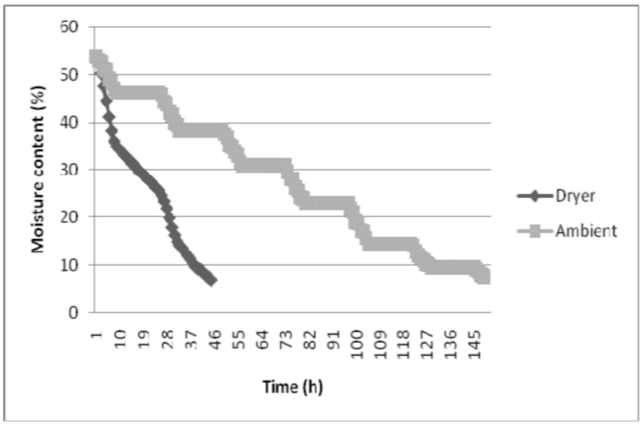

Fig. 6 Variation of Moisture Content with Time

The fig.6 shows the variation of moisture content of coconuts dried inside the dryer (with biomass backup heater) and in the open sun during the experimental period. During the first 24 hours of the experiment (first day), the moisture content of the coconuts inside the dryer reduced from 53.84% to 25.56%. However, for the open sun dried coconuts, moisture content was reduced from 53.84% to 46.32%. During the next 24 hours of the experiment (second day), the moisture content of the coconuts inside the dryer reduced from 25.56% to 7.003%. By the end of second day, the moisture content of the coconuts inside the dryer was reduced to 7.003% which is the optimum level of moisture content for production of oil from coconuts. But for the open sun dried coconuts, moisture content is reduced from 46.32% to 38.46%. During the third day, fourth day and fifth day of the experiment, the moisture content of open sun dried coconuts reduced from 38.46% to 30.82%, from 30.82% to 22.98% and from 22.98% to 14.42% respectively. During the sixth day and seventh day of the experiment, the moisture content of the open sun dried coconuts reduced from 14.42% to 9.5% and from 9.5% to 7.4% respectively. By the mid of the seventh day, the moisture content of the open sun dried coconuts was reduced to 7.4% which is the maximum rate of moisture removal from coconuts. In the open sun drying, the products which has an initial moisture content of 53.84%, is reduced to 7.4% for time period of 148 hours, while in the solar tunnel dryer, the products which has an initial moisture content of 53.84%, is reduced to 7.003% for time period of 44 hours which clearly reveals that the coconuts were dried at an earlier time in the solar tunnel greenhouse dryer than the open sun drying method. This reduced drying time is achieved as a result of steady temperature rise inside the solar tunnel greenhouse dryer even in the absence of sunlight (after 5PM) which is due to the biomass backup heater coupled to the solar tunnel greenhouse dryer and also due to the greenhouse effect. Thus the biomass heater helps in the drying of coconuts at a very quicker time than the conventional drying method.

IX. CONCLUSION

Experiments were conducted in a natural circulation solar tunnel greenhouse dryer coupled with biomass backup heater for the studying the drying characteristics of coconuts during the month of January 2014. About 5000 coconuts were loaded into the solar tunnel greenhouse dryer and it was repeated for three trials. The coconuts which has an initial moisture content of 53.84% was reduced to a final moisture content of 7.003% in the solar tunnel greenhouse dryer over a time period of 44 hours. This reduced drying time is mainly because of the biomass heater coupled to the solar tunnel greenhouse dryer. This biomass heater provided heat to the dryer during the time period where there would be a drop in sunshine (after 5PM). This enables the dryer to remove the moisture content from the coconuts at an earlier time than the open sun drying method where it took 148 hours for the reduction of moisture content of the coconuts to the same level. The reduced drying time in the dryer is due to the low relative humidity and high temperature maintained constantly inside the dryer with the help of biomass heater and greenhouse effect. Thus the solar tunnel greenhouse dryer coupled with biomass backup heater dry the coconuts at a very quicker time than the open sun drying method.

Fig. 7 Drying of Coconuts in Solar Tunnel Greenhouse Dryer Coupled with Biomass Backup Heater

The fig.7 shows the drying of coconuts in the solar tunnel greenhouse dryer coupled with biomass backup heater during the month of January 2014. Also, it is clear that the solar tunnel dried coconuts are superior in quality than the open sun dried coconuts (fig.8). The superior quality of the coconuts in the dryer is mainly due to the fact that there was no contamination, windborne disturbances such as dirt & dust, bacterial and fungal infections and damage by birds, insects and animals which were seen predominantly in the open sun drying method. The high temperature and low relative humidity inside the dryer prevented the fungal and bacterial infections and hence the dryer dried the coconuts without any quality degradation. The practice of sulphur fumigation is not needed for the coconuts dried inside the dryer. Thus the coconuts dried in the solar tunnel greenhouse dryer will be of superior quality than the open sun dried coconuts.

Fig. 8 Comparison of Coconuts Dried in Solar Tunnel Greenhouse Dryer Coupled with Biomass Backup Heater and Open Sun Drying Method

The fig.8 shows the coconuts dried in solar tunnel greenhouse dryer and open sun drying method during the experimental period (22-24th January, 2014).

ACKNOWLEDGMENT

The financial support by Science for Equity, Empowerment & Development division of Department of Science and Technology, Govt. of India, New Delhi for this study in the framework of the project, "Popularization of solar tunnel dryers for copra production in Pollachi region (Tamil Nadu)" is gratefully acknowledged.

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