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# Experimental Studies on Drying Characteristics of Coconuts in a Solar Tunnel Greenhouse Dryer

**S. Arun, K. Velmurugan, S. Shankar Balaji**

***Abstract*— A natural convection solar tunnel greenhouse dryer was designed and fabricated for studying the drying characteristics of coconuts in Pollachi region of Tamil Nadu. Three experimental runs with 5000 coconuts were carried out in the dryer during the month of March 2014. 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 7.4% (w.b.) in the solar tunnel greenhouse dryer for a time period of 56 hours whereas the open sun drying method took 147 hours for the same. Also, the quality of dried coconuts in the solar tunnel greenhouse dryer was found to be free from fungal and bacterial infections which prove the possibility of production of superior quality coconuts from the dryer than that of open sun drying method.***

***Index Terms*: Coconuts, Drying Time, Moisture Content, Open Sun Drying, Quality, Solar Tunnel Greenhouse Dryer.**

## 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. As the development of efficient and inexpensive equipment for the drying of agricultural and marine products using solar power evolved thereby improving the quality of the products as well as improving the quality of life. Drying of products is one of the oldest methods of preserving food. Dehydration of fruits and vegetables reduces moisture level to the extent where there will be no effect of microbial and fungal infections. Also, drying of products helps in reducing the packaging size thereby reducing the volume for packaging and reduces the transportation costs. Drying is an energy intensive operation of industrial significance. 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.

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Copra, the dried edible part of coconut is produced after drying of coconut. In India, about 30 per cent of coconut production goes for producing copra for oil extraction while the remaining is used for edible oil, tender coconut and for producing other value-added products. Though only 30 per cent of the coconut goes for oil extraction, the farm level price of coconut is purely based on the oil price, resulting in unstable revenue to the coconut farmers. In order to obtain the oil from copra, the moisture content of the coconuts has to be reduced to an optimum level where it will be suitable for production of oil. In the developing countries like India, the traditional method of reducing the moisture content of the coconuts is by open sun drying. During traditional open sun drying, the farmers spread coconut on mats, cement floors, roof tops or even on soil along the roadsides so as to expose to solar intensity until the completion of drying. In this method the samples are exposed to direct sun light and consequently the coconut pieces heat up and the internal temperature rises without regulation which destroys colour, vitamins and flavor giving rise to low quality production that cannot compete with the mainland product. Also, there will be contamination by insects, birds and windborne problems like dust, dirt etc., which ultimately degrades the quality of copra to a greater level. To overcome the practical difficulties of open sun drying, a natural convection solar tunnel greenhouse dryer was designed and developed in Negamam, Pollachi. It basically operates on greenhouse effect. A greenhouse is essentially an enclosed structure which traps the short wavelength solar radiation and stores the long wavelength thermal radiation to create a favorable micro-climate for higher productivity. 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. Thus, the temperature inside the dryer will be increasing steadily, thereby ensuring quicker drying of the products than the open sun drying method. Reference [1] shows the dehydration of crops using solar dryer. Numerous studies on drying of crops in solar tunnel dryer have been made so far [1]-[5]. Various investigators have studied the greenhouse for crop drying [6], [7] & [8]. Reference [9] shows a solar dryer with a greenhouse as a collector for drying grapes. Reference [10] shows the solar energy collection characteristics of a fibre reinforced plastic drying house for paddy drying. This study was undertaken to investigate the drying characteristics of coconuts in a solar tunnel greenhouse dryer and also to compare the quality of copra obtained from open sun drying method and solar tunnel dryer.

## II. EXPERIMENTAL SECTION

Experiments were carried out under meteorological conditions of Pollachi (latitude, 10.39°N; longitude, 77.03°E) in India during the summer months 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 (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.

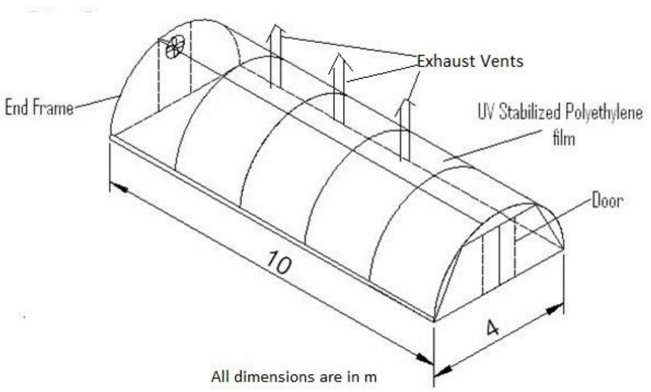


**Fig. 1 Solar Tunnel Greenhouse Dryer**

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

Experiments were conducted during 28-30$^{th}$ of March 2014 for the dryer placed at Negamam village of Pollachi, India. 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, exhaust vents were opened to exhaust initial high humid air. Solar intensity, ambient wet and dry bulb temperatures were measured every 1 h interval till end of drying.

## 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*

The fig.2 shows the variation of solar intensity, ambient temperature and dryer temperature during the experimental period (28-30$^{th}$ March, 2014). During the first day, the solar intensity varied between 278 W/m$^2$ and 779 W/m$^2$, the ambient temperature varied between 29°C and 37°C with a peak value of 37°C at around 1.00 p.m. and the dryer temperature varied between 42°C and 62°C with a peak value of 62°C at around 1.00p.m.

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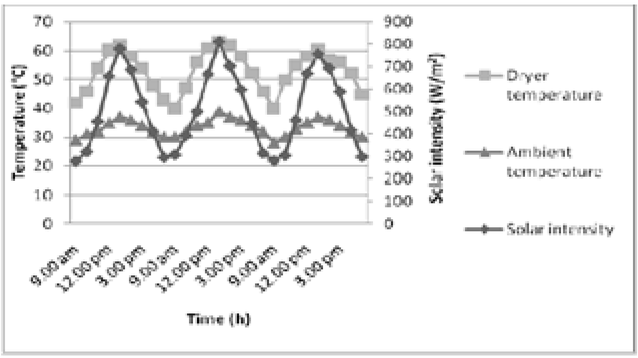


**Fig. 2 Variation of Solar Intensity and Temperature with Time**

During the second day, the solar intensity varied between 307 W/m$^2$ and 810 W/m$^2$, the ambient temperature varied between 30°C and 39°C with a peak value of 39°C at around 1.00 p.m. and the dryer temperature varied between 40°C and 63°C with a peak value of 63°C at around 1.00p.m. During the third day, the solar intensity varied between 281 W/m$^2$ and 755 W/m$^2$, the ambient temperature varied between 28°C and 37°C with a peak value of 37°C at around 1.00 p.m. and the dryer temperature varied between 40°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 12°C to 23°C more than the ambient temperature in all the three days of experiment which shows that the dryer temperature got increased effectively due to the green house effect thereby drying the products inside the drier at an earlier time. Also, the drier temperature varied according to the solar intensity during this experimental period. The maximum solar radiation observed was about 810 W/m$^2$.

### *C. Variation of Relative Humidity with Time*

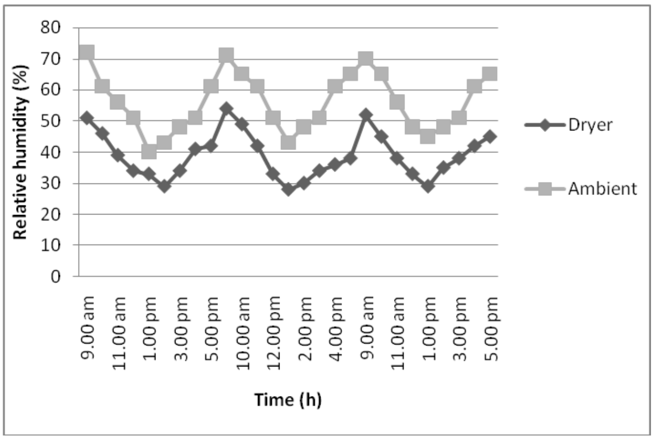


**Fig. 3 Variation of Relative Humidity with Time**

The fig.3 shows the variation of dryer relative humidity and ambient relative humidity during the experimental period. During the first day, the relative humidity of the dryer varied between 29% and 51% whereas the ambient relative humidity varies between 40 % and 72%. During the second day, the relative humidity of the dryer varied between 28% and 54% whereas the ambient relative humidity varied between 43% and 71%. During the third day, the relative humidity of the dryer varied between 29% and 52% whereas the ambient relative humidity varied between 45% and 70%. In all the three days of the experimental period, the relative humidity of the dryer was less than that of ambient relative humidity due to the high temperature prevailing inside the dryer (due to the green house effect). This ensures that in solar tunnel dryer, the coconuts can be dried at a quicker time than the open sun drying method.

### *D. Variation of air velocity with time*

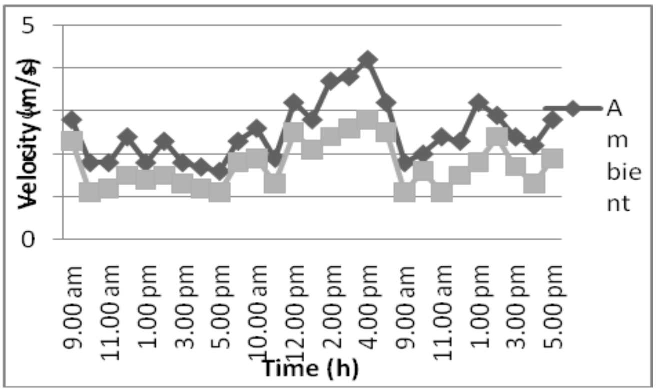


**Fig. 4 Variation of Air Velocity with Time**

The fig.4 shows the variation of ambient air velocity and dryer air velocity during the experimental period. During the first day, the ambient air velocity varied between 1.6 m/s and 2.8 m/s whereas the dryer air velocity varied between 1.1 m/s and 2.3 m/s. During the second day, the ambient air velocity varied between 1.9 m/s and 4.2 m/s whereas the dryer air velocity varied between 1.3 m/s and 2.8 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 Sheet Temperature with Time*

The fig.5 shows variation of sheet temperature inside and outside of the dryer with time during the experimental period. During the first day, the sheet temperature inside the dryer varies from 41°C and 63°C whereas for sheet outside the dryer, the temperature varies from 30°C and 38°C. During the second day, the sheet temperature inside the dryer varies from 39°C and 64°C whereas for sheet outside the dryer, the temperature varies from 31°C and 41°C. During the third day, the sheet temperature inside the dryer varies from 38°C and 61°C whereas for sheet outside the dryer, the temperature varies from 29°C and 39°C. In all the three days, the sheet temperature inside the dryer was higher than that of the sheet temperature outside the dryer which is mainly due to the green
house effect inside the dryer.

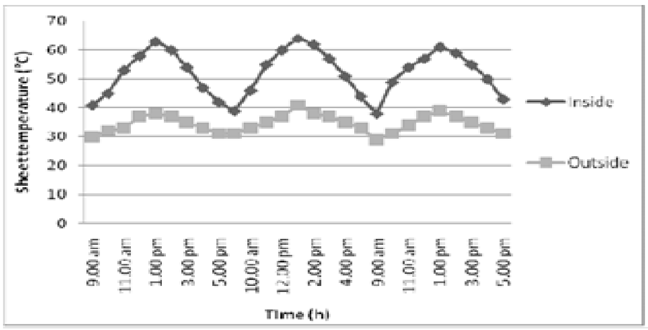


**Fig. 5 Variation of Sheet Temperature with Time**

### *F. Variation of Floor Temperature with Time*

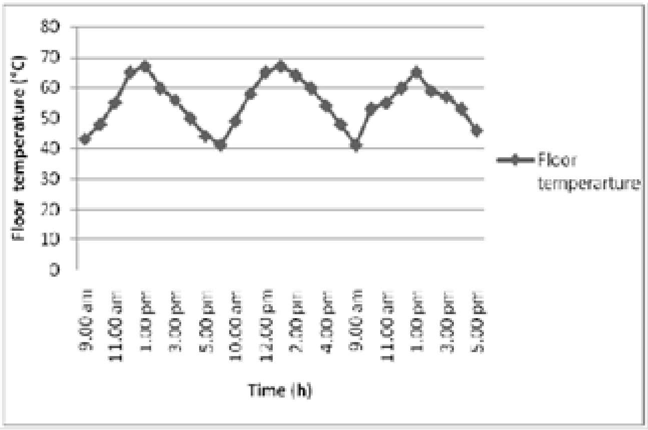


**Fig. 6 Variation of Floor Temperature with Time**

The fig.6 shows the variation of floor temperature of the dryer with time during the experimental period. During the three days of the experimental period, the floor temperature varied from 43°C to 67°C, 41°C to 67°C and 41°C to 65°C respectively.

### *G. Variation of Product Temperature with Time*

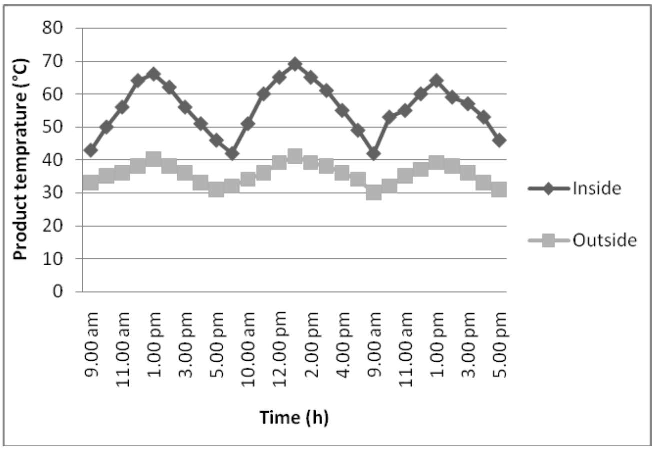


**Fig. 7 Variation of Product Temperature with Time**

The fig.7 shows the variation of product (coconuts) temperature inside and outside the dryer over time during the experimental period. During the first day, the product temperature inside and outside the dryer varies from 43°C to 66°C and 31°C to 40°C respectively. During the second day, the product temperature inside and outside the dryer varies from 42°C to 69°C and 32°C to 41°C respectively. During the third day, the product temperature inside and outside the dryer varies from 42°C to 64°C and 30°C to 49°C respectively. The temperature of the product inside the dryer was higher than that of the products outside the dryer which is due to the high temperature environment prevailing inside the dryer (green house effect).

### *H. Variation of Moisture Content with Time*

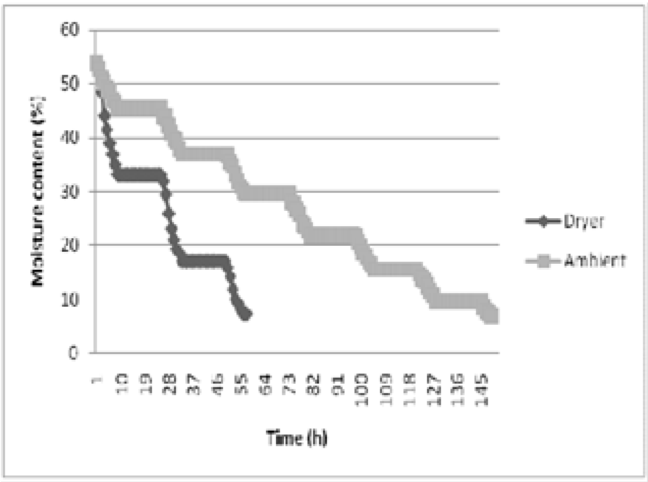


**Fig. 8 Variation of Moisture Content with Time**

The fig.8 shows the variation of moisture content of coconuts dried inside the dryer and in the open sun during the experimental period. During the first day, the moisture content of the coconuts inside the dryer reduced from 53.84% to 33.21% whereas for the open sun dried coconuts, it is reduced from 53.84% to 45.5%. During the second day, the moisture content of the coconuts inside the dryer reduced from 33.21% to 17.16% whereas for the open sun dried coconuts, it is reduced from 45.5% to 37%. By the third day, the moisture content of the coconuts inside the dryer was reduced to 7.4% which was the maximum level of moisture removal from coconuts for the production of coconut oil from it. During the third day and fourth day of the experiment, the moisture content of open sun dried coconuts reduced from 37% to 29.68% and from 29.68% to 22% respectively. During the fifth day, sixth day and seventh day of the experiment, the moisture content of open sun dried coconuts reduced from 22% to 15.5%, from 15.5% to 9.89% and from 9.89% 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 147 hours, while in the solar tunnel dryer, the products which has an initial moisture content of 53.84%, is reduced to 7.4% for time period of 56 hours. It can be seen that the solar tunnel dryer dried the coconuts at an earlier time than that of open sun drying method which is due to lower relative humidity and higher temperature prevailing inside the dryer all the time (green house effect).

## IX. CONCLUSION

The fig.9 shows the drying of coconuts inside the solar tunnel greenhouse dryer during the month of March 2014. Experiments were conducted in a natural circulation solar tunnel greenhouse dryer for the studying the drying characteristics of coconuts in a solar tunnel greenhouse dryer during the months of March 2014.


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**Fig. 9 Drying of Coconuts Inside the Solar Tunnel Dryer**

Three full scale trails with 5000 coconuts were loaded into the solar tunnel greenhouse dryer. The initial moisture content of the coconuts was found to be 53.84% which is then reduced to a final moisture content of 7.4% in the solar tunnel greenhouse dryer for a time period of 56 hours which is lesser than that of open sun drying method where it took 147 hours for reducing the moisture content of coconuts to the same level. The reduced drying time of coconuts in the solar tunnel greenhouse dryer is mainly because of the high temperature and lower relative humidity prevailing inside the dryer which is due to the greenhouse effect.

**Fig. 10 Quality Comparison between Solar Tunnel Dried and Open Sun Dried Coconuts**

From this fig.10, it is clear that the solar tunnel dried coconuts are superior in quality than the open sun dried coconuts. This is due to the fact that in open sun drying, the quality degradation of coconuts was primarily due to the lower atmospheric temperature and higher relative humidity which paved the way for the fungal and bacterial infection in coconuts whereas in solar tunnel dryer, the temperature will be higher and the relative humidity will be lesser which is sufficient enough to dry the coconuts at an earlier time than the open sun drying without any degradation in quality. Thus the products dried in the solar tunnel dryer will be always superior in quality than the ones which are dried in open sun drying method.

## X. ACKNOWLEDGMENT

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