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Research Article

DESIGN AND DEVELOPMENT OF SOLAR TUNNEL DRYER WITH CONTROL SYSTEM FOR LARGE SCALE DRYING OF AGRO PRODUCTS

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Abstract- Drying of agro products is one of the most important post harvest operations in agricultural processing. This paper presents the design. Development and experimental investigations of solar tunnel dryer with control system for drying agro product (coconuts). The experiments were conducted in a hemispherical shaped solar tunnel dryer for drying coconuts and compared with open sun drying. The weather parameters such as ambient temperature and ambient RH, wind velocity, wind direction, solar radiation and rainfall were monitored along with dryer temperature and relative humidity. The dryer temperature and relative humidity was monitored and controlled with control system using exhaust fans at chimneys. The coconuts were loaded in a tray and trolley system inside the dryer and drying experiments were performed between 9.00 a.m. to 5.00 p.m. It was found that the time required to dry coconuts from initial moisture content of 110.5 per cent (d.b) to a final moisture content of around 7.36 per cent (d.b) in solar tunnel drying mode was 49.5 hours, whereas 80 hours for open sun drying mode. The drying characteristics such as moisture reduction, drying rate and moisture ratio were analyzed.

Keywords- Coconuts, Solar Tunnel Dryer, Moisture, Drying Rate, Automatic Control System

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Introduction

Drying is the most energy intensive method for effective vaporization of moisture in the product by means of supplying energy i.e., by passing hot air through the surface of the products thereby the product gets heated up and releases the moisture to attain the desired moisture content. Different kinds of classifications are available for drying systems with number of dryers are developed and available for drying various agro products. Dryers may be classified as open-air or sun, fuel fired or kiln, electric and solar dryers. Open air or sun drying is cheap but it has the major problem of slow and intermittent drying, no protection over rain, contamination, undesirable quality change and non uniformity of dried products [1]. The fuel fired or kiln drying using fossil fuels or wood contributes to environmental degradation by means of deforestation and emission of green house gases and particulate matter. Electric dryers are not cost effective and it is limited to areas where there is uninterrupted power supply. In contrast, solar dryers are environment friendly, cost effective and available everywhere. Solar energy is one of the most promising renewable energy sources. In order to overcome the problems of open sun drying and other conventional drying methods, the solar dryer was first developed by Everitt and Stanley in 1976 [2]. Drying using solar dryers is the method of controlled sun drying to enhance the quality of dried products. Solar dryers are generally classified, depending on the mode of heating or operation as direct, indirect and mixed mode systems with natural or forced circulation of the drying air [3]. Different types of solar dryers were designed and developed by eminent researchers for drying various agro products like Chilli [4,5], mango [6], grapes [7], ginger [8], paddy [9], copra [10,11]. Dryers were designed depending upon the various properties of product to be dried such as initial and final moisture content, quantity of the product, type of product etc.,

Solar tunnel dryers were mainly used for large scale drying and designed for drying huge quantity of products in a single batch.

Coconut is one of the most important and economically valuable agricultural produce processed to copra in a large scale. Of the world production of coconut, more than 50 per cent is processed into copra. Copra is the dried product of coconut used for both preservation and for extraction of coconut oil. The fresh coconut is converted to copra through various processes like husk removal, breaking into two, shell removal and drying. Coconut has an initial moisture content of 55 per cent (w.b), which is to be reduced to 6 per cent (w.b) for obtaining good quality copra [12]. In order to get good quality copra for export or oil production, coconuts need to be dried to its final moisture content as fast as possible.

Materials and Methods

The experimental study was carried out in Department of Bioenergy, Tamil Nadu Agricultural University, Coimbatore. The coconuts were procured from M/S Annur Agro Oil Industry, Vadakkalur village, Annur, Coimbatore district. The industry is a coconut oil producing industry with daily processing capacity of 20000 coconuts.

Design of Solar Tunnel Dryer

The solar tunnel dryer was designed keeping in view of the following criteria.

1. The drying system should be flexible, so that it can be used for other agricultural products too.
2. It should be durable, simple and can be manufactured using local materials and manufacturing technologies.

3. Drying should take place such that it could not affect the product.
4. Desired moisture content has to be obtained in minimum drying period.
5. Large scale loading and unloading of products for drying is quite easy.

With the above design criteria, following assumptions of certain parameters were made to carryout design calculation.

i. Quantity of material to be dried = 1000 kg
ii. Initial moisture content of coconut (w.b) = 55 per cent
iii. Final moisture content of coconut (w.b) = 6 per cent
iv. Drying period = 30 hours
v. Initial temperature of coconut = 27 °C
vi. Final temperature of coconut, Tp = 65 °C
vii. Latent heat of vaporization of water, L = 2260 kJ kg^{-1}
viii. Specific heat of water, Cpw = 4.186 kJ $kg^{-1}K$
ix. Specific heat of coconut, Cp = 2.93 kJ $kg^{-1}K$
x. Ambient temperature, Ta = 27 °C

Quantity of water to be removed

The solar tunnel dryer was designed to dry 1000 kg of coconut and the amount of water to be removed from the coconut was calculated as described by Sahay and Singh, 1994 [13].

Amount of initial water content is calculated as:

$$M = \frac{(m_1 \times x)}{100}$$

Where M is the initial water content in the product, g, m_1 is the initial moisture, %, x is the quantity of product to be dried.

Mass of dry matter is calculated as:

$$M_d = x - M$$

Where M_d is the mass of dry matter

Initial moisture content (d.b) is

$$M_{i,db} = \frac{m_1}{(100 - m_1)} \times 100$$

Where $M_{i,db}$ is the initial moisture content on dry basis, %.

Final moisture content (d.b) is

$$M_{f,db} = \frac{m_2}{(100 - m_2)} \times 100$$

Where $M_{f,db}$ is the final moisture content on dry basis, % and m_2 is the final moisture content on wet basis, %.

The amount of waster to be removed during drying is calculated as:

$$M_w = M_d \frac{(m_i - m_f)_{db}}{100}$$

Where M_w is the quantity of water to be removed from product to attain desired moisture, g.

Heat required for drying

Sensible heat of the product is calculated as:

$$S_1 = m_p \times C_p \times (T_p - T_i)$$

Where S_1 is sensible heat of product in kJ, m_p is mass of dry matter of product kg, C_p is specific heat of product in kJ per kg °C, T_p is final temperature of product in °C and T_i is initial temperature of product in °C.

Sensible heat of water in the product is calculated as:

$$S_2 = m_w \times C_w \times (T_w - T_i)$$

where S_2 is sensible heat for water in product in kJ, m_w is initial water content kg, C_w is specific heat of water kJ per kg °C, T_w is final temperature of water in product in °C and T_i is initial temperature of product in °C.

Latent heat of water is calculated as:

$$S_3 = m_w \times L$$

Where S_3 is latent heat of product in kJ, mw is quantity of water to be removed in kg and L is latent heat of water in kJ per kg.

Total heat required for drying is

$$S = S_1 + S_2 + S_3$$

Net heat required for drying is calculated as

$$Q = S / Heatloss$$

Heat supplied by air

Heat supplied by air, Q is calculated using the following equation

$$G \times S \times (T_2 - T_1) \times t_d$$

where,

Q is the heat supplied by air, kcal, G is the air flow rate, kg h^{-1} and S is the humid heat of the ambient air. S is calculated as

S = (0.24 + 0.45 H), kcal kg^{-1} dry air K

T_2 is the temperature at the outlet of the dryer, °C, T_1 is the temperature of the heated air, °C, t_d is the drying time, h and H is the absolute humidity of ambient air, kg kg^{-1} of dry air.

Calculation of air flow rate

By applying heat balance, heat required for drying must be equal to the heat supplied by air for drying [14]

Heat required for drying is equal to Heat supplied by drying air. Hence,

$$Q = G \times S \times (T_2 - T_1) \times t_d$$

$$G = \frac{Q}{S \times (T_2 - T_1) \times t_d}$$

Area of solar collector

The area occupied by the solar collector is calculated as [15]:

$$A = \frac{(m_w \times L)}{I_s \times \eta}$$

Where m_w is the mass of water to be removed, kg, L is the latent heat of vaporization, MJ kg^{-1}, η is the efficiency of the dryer, per cent (50 per cent approx) and I_s is the daily solar insolation, MJ m^{-2}

Assume height of solar tunnel dryer a 2.0 m and the length of solar tunnel dryer is calculates using

$$L = \frac{Area}{h \times \pi}$$

Similarly, the width of solar tunnel dryer is assumed as constant value of 3.75 m. The floor area of solar tunnel dryer is calculated as follows:

$$FloorArea = W \times L$$

Chimney design

Since airflow in the dryer takes places due to the draft caused by the density difference between outside cold air and inside hot air, a natural draft uses the basic law that warm air rises. Air as it is warmed expands and becomes lighter in mass. Colder, heavier air pushes in under it and forces it up [16]. This causes a draft.

Mass of air required is calculated as follows:

$$q_a = \frac{M_w \times L}{C_{pa} \times (T_c - Ta)}$$

Where M_w is the quantity of water to be removed from product in kg, C_{pa} is specific heat of air in kJ per kg°C, T_c is chimney temperature in °C and T_a is ambient temperature in °C

Mass of exit air from dryer,

$$q = M_w + q_a$$

Where M_w is the quantity of water to be removed from product in kg and q_a is mass of air required in kg

Assume height of the chimney = 4.0 m (four chimneys of 1.00 m height)

Draft produced,

$$D_p = H \times g \times (\rho_i - \rho_e)$$

Where D_p is actual draft produced in kg per m per s^2 and H is height of chimney in m, g is gravitational constant, ρ_i is density if inlet air in kg per m^3 and ρ_e is density of exit air in kg per m^3.

$$D_a = 0.75 \times D_p$$

Where D_a is actual draft in kg per m per s^2

Velocity of exit air,

$$V = \sqrt{\frac{2D_a}{\rho_e}}$$

Where V is velocity of exit air in m per s

Volume of exit air,

$$V_e = \frac{q}{\rho_e}$$

Rate of exit air,

$$Q_a = \frac{V_e}{t}$$

Where Q_a is rate of exit air in chimneys m^3 per h and t is time of drying in h

Rate of exit air for single chimney,

$$Q_c = \frac{Q_a}{n}$$

Where Q_c is rate of exit air in single chimney and n is number of chimneys

Area of chimney,

$$a_c = \frac{Q_c}{V}$$

Where a_c is the area of chimney

Diameter of chimney,

$$d_c = \sqrt{\frac{4 \times a_c}{\pi}}$$

Where d_c is diameter of chimney

Dimensions of solar tunnel dryer

Table-1 *Design dimensions of solar tunnel dryer*

Components	Specifications
Length of solar tunnel dryer	18.0 m
Width of solar tunnel dryer	3.75 m
Height of solar tunnel dryer	2 m
Area of solar tunnel dryer	117.8 m^2
Air flow rate	23.3 m^3 min^{-1}
Number of chimneys	4
Height of chimney	1.00 m
Diameter of chimney	0.20 m
Tray size	1m x 1m
Trolley	2m x 1m
Number of trays	6 trays per trolley
Number of trolley	12

Description of solar tunnel dryer

The solar tunnel dryer mainly consists of a semi cylindrical pipe structure covered with U.V. stabilized Polyethylene sheet. The solar radiation is transmitted through the UV sheet, which has the property of transferring short-wave radiations and opaque for long-wave radiations. When solar radiation in the form of short-wave radiation transmitted through the UV sheet, it gets converted to long-wave radiation inside the solar tunnel dryer. Therefore, the radiation is trapped inside the dryer and increases the temperature of the dryer.

It was reported that the East-West orientation of the solar tunnel dryer is more appropriate than any other orientation [17]. The orientation of the solar dryer was towards east-west direction, since the light transmittance was high in this direction and maximum exposure to solar radiation was possible.

Solar tunnel dryer consists of a drying chamber of 18.0 m x 3.75 m. The height of the dryer is 2.0 m. it is semi cylindrical shaped tunnel made of pipe frame structure covered with UV stabilized semi transparent polyethylene sheet of 200 micron thickness. It consists of metallic frame, developed through 13 hoops of G.I pipes bent to 3.75 m diameter, these hoops are having horizontal spacing of 1.5 m, over which UV sheet is wrapped.

The constructional and structural components of solar tunnel dryer are pipe foundation, hoops, floor, lateral support, UV stabilized polyethylene sheet assembly, end frames and doors.

Foundation provides anchorage to the super structure and supports the components of solar tunnel dryer. They provide a firm support to the hoops in the structure. The hoops are spaced in between 1.5 m interval with 'B' class G.I. pipes of 25 mm diameter and 0.61 m length is used. A 10 cm piece of mild steel flat of 25 mm x 3 mm is centrally welded to the one end of the pipe and 8 mm diameter holes drilled at 10 cm distance from the other end. The flat welded end is fixed in the hole to a depth of 45 cm grounding with cement concrete masonry of 1:5:10. The foundation pipes are spaced 1.5 m apart in parallel rows. Special care is taken to ensure that the top of all foundation pipes is at the same elevation.

Hoops are the integral part of the structure of solar tunnel dryer. These are semi circular in shape and are formed using bending galvanized iron class "B" pipe (15 mm dia and 5.9 m length). The long pipes are fed into the bending machine and uniform bending is achieved in semi circular shape. About 30 cm length on each end is kept unbent which enables the end to easily fit into the foundation pipe.

End frames are made of aluminium members fitted on both ends of solar tunnel dryer. The end frame structure is having provisions for door and exhaust fan fixtures.

One end of the dryer consists of a double door of 2.15 m x 1.65 m size made up of mild steel frame with inner aluminium tubes for loading and unloading the trays and trolley system. The door is covered with UV sheet and fixed firmly using zig zag spring.

UV stabilized polyethylene sheets of 200 micron thickness are used as a cover material, which has a transmissivity of 90 per cent. Its higher strength and low cost have made it most popular replacement for glass cover material. After completing the superstructure, polyethylene sheet is spread from one end to the other without any wrinkles. The polyethylene film was covered on all sides of solar tunnel dryer and fixed with the end frames using zig-zag spring steel. During sunshine hours, the short wave radiations are entrapped through the UV sheet and cause an increase in temperature inside the dryer. The heated air from the bottom while passing over the products absorbs the moisture and enhances the drying rate of the produce inside the dryer.

Ventilation is provided at the bottom of the solar tunnel dryer using woven fabric of synthetic filament yarn mesh of 0.3 m x 36.5 m size. It acts as a fresh air inlet to the dryer and also insect trapper. The fresh air enters the drying chamber through the mesh and gets heated. The heated air moved up, passed through agro product, supplied heat energy to the product, removed the moisture from the product surface and escaped through the chimney provided at top of tunnel.

Equi-spaced holes of 0.2 m diameter are fitted with four aluminium chimneys and cowl to protect against rain and natural disaster was provided for natural convection. The heated air inside the dryer is passed over the product and evaporates the moisture. The heated air along with moisture moves upwards due to the natural draft created by chimneys. The exhaust fans of 45 Watts capacity was provided at each chimneys for automatically controlling the temperature and relative humidity inside the solar tunnel dryer.

The floor of the solar tunnel dryer is filled with sand for about 3 inch thickness and over the sand black colour kadappah slabs were laid for absorbing more solar radiation to increase the temperature inside the dryer. The purpose of filling sand and laying kadappah slab is for absorbing extra energy during day time and storing the extra energy, which can be used for drying whenever the solar radiation is poor. Area of drying floor is 6.5 m^2.

The trays were made of 8 SWG thick galvanized iron mesh with dimension of 1m x 1m. The trolleys are made of mild steel L angle of 2m x 1m x 1.35m size. Each trolley can hold 6 trays with 2 trays at each level of 0.4 m, 0.9m and 1.3m height. The trolleys are provided with 3 inch hard wheels for easy loading inside solar tunnel dryer. All the trays and trolleys are coated with red oxide and black enamel paint for absorption of heat. The arrangement of trays and trolleys were shown in [Fig-1].

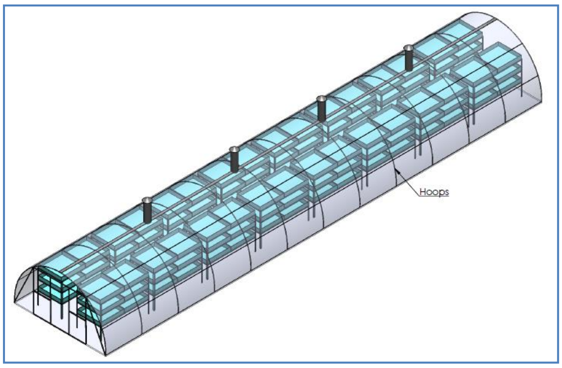

Fig-1 Arrangement of trays and trolleys in solar tunnel dryer for drying coconuts

Instrumentation

Temperature and relative humidity inside solar tunnel dryer was recorded using thin film RTD sensor and thin film polymer capacitor respectively with temperature measuring range of 0 °C to 100 °C with an accuracy of 0.3°C and relative humidity range of 0 to 100 per cent with ± 2 per cent accuracy. Temperature of exhaust air at chimney of solar tunnel dryer, ambient temperature, ambient relative humidity, solar radiation and wind velocity was also recorded. The weather parameters such as ambient temperature and ambient RH, wind velocity, wind direction, solar radiation and rainfall details were measured using an automatic weather station installed at the project location.

Temperature and relative humidity control system

The chimneys of solar tunnel dryer were fixed with exhaust fans of 4x45 Watts capacity. The exhaust fan was used to automatically control the temperature and relative humidity inside the dryer. There was a set point for temperature and relative humidity, which was fixed manually based on the agro product and its required drying temperature. If the average temperature and relative humidity exceeds the set point, the signal was given to exhaust fans through computer programming and the exhaust fans were switched on and if it reduced below set point, the exhaust fans were switched off.

Results

In this investigation the solar tunnel dryer was installed at Renewable Energy Park, Department of Bioenergy, TNAU, Coimbatore, Tamil Nadu and its performance was tested for drying of coconuts [Fig-2]. The dryer was oriented east-west direction and there was no shadow effect on the tunnel by trees or buildings. The coconuts were dried on the floor of the dryer. The temperature and relative humidity were analysed at various points throughout the length of solar tunnel dryer. Other parameters such as ambient temperature, ambient relative humidity, solar intensity and solar tunnel dryer average temperature that affect the performance of the dryer were measured at every one hour interval.

The coconuts were spread inside tunnel dryer floor and dried from initial moisture content of 110.5 per cent (d.b) to a final moisture content of 7.36 per cent (d.b). Drying and weather parameters were recorded from morning 9:00 AM to evening 5:00 PM. The loss in mass was recorded for every two hours time interval and the decrease in moisture ratio and drying rate were calculated. The drying characteristics such as moisture content, drying time, drying rate and the effects of weather parameters such as temperature, relative humidity on drying are presented and discussed.

Similarly, coconuts were also dried in open sun from 9:00 AM to 5:00 PM for comparing the performance and drying characteristics of solar tunnel dryer.

Open sun drying

The experiments on open sun drying of coconuts were conducted by keeping the broken and dewatered coconuts in open sun with kernel facing the sun during day time from 9:00 AM to 5:00 PM. The time required to dry coconuts from its initial moisture content to require final moisture content in open sun drying mode was estimated to be 80 hours. The ambient temperature varied from 24 °C to 32.3 °C. The ambient relative humidity varied from 50 per cent to 89 percent with the maximum solar intensity of 1007 W m^{-2}. Moisture content versus drying time for coconuts in open sun drying mode is shown in [Fig-3(a)], which showed that the moisture removal was not uniform during drying process in open sun drying. It is seen that lower quantum of moisture removed during the beginning and end of everyday and recorded a maximum value in the afternoon from 1:00 PM to 3:00 PM. The maximum moisture removal was recorded during afternoon of first and second day and it was estimated as 7.37 per cent. It was observed that the first, second, fifth and sixth day storage of coconuts during night hours resulted in desorption of moisture and it was absorbed 1.05 per cent, 0.4 per cent, 1 per cent and 2.1 per cent moisture respectively, which follows the similar pattern of open sun drying study conducted by Thiruchelvam Thanaraj *et al*. 2006 [18].

The curve for drying rate versus drying time in open drying [Fig-3(b)], recorded seven peak levels of drying rate recorded during the total drying period of 80 hours. The maximum drying rate of 0.034 g of moisture per g of dry matter per hour recorded during first day of drying process and minimum drying rate was reached at 80th hour (end of drying period) as 0.013 g of moisture per g of dry matter per hour. At the beginning of drying process, when the moisture content was high, drying rate was also very high and as the moisture content approached the equilibrium moisture content, drying rate was very low. The moisture ratio versus drying time for drying of coconuts in open sun drying in [Fig-3(c)], which showed that the moisture ratio of coconuts reduced exponentially as the drying time increased.

Solar tunnel drying

The time required to dry coconuts from initial moisture content of 110.5 per cent (d.b) to a final moisture content of around 7.36 per cent (d.b) was 49.5 hours. This confirmed with the results of copra drying study conducted by other authors [19].

Fig-2 Coconut drying using trays and trolleys in solar tunnel dryer installed at TNAU, Coimbatore

Effect of weather parameters inside solar tunnel dryer

The ambient temperature varied from 23.8 °C to a maximum of 30.7 °C. The ambient relative humidity varied from 88 per cent (during rainfall) to 52 per cent during peak sunshine hours. The solar intensity varied from 33Wm-2 to 993Wm^{-2}.The temperature inside the solar tunnel dryer depends on solar radiation, ambient temperature and relative humidity. It was observed that the ambient temperature varied from a minimum of 23.8 °C to a maximum of 30.7 °C. During this period, the solar tunnel dryer gained the maximum energy from sun. Similarly, the temperature inside solar tunnel dryer varied from a minimum of 31 °C to a maximum of 65 °C. It was thus observed that the temperature inside solar tunnel dryer was always higher than the ambient temperature and the difference decreased towards sunset. The results showed that the temperature inside the solar tunnel dryer was on an average 30 °C higher than the ambient temperature.

The ambient relative humidity varied from 52 per cent to 89 per cent. The relative humidity was very high when the temperature was low and similar trend was observed inside solar tunnel dryer. The relative humidity inside solar tunnel dryer recorded a maximum of 96 per cent and a minimum of 43 per cent. During afternoon, the relative humidity inside solar tunnel dryer was reduced drastically compared to the ambient relative humidity. This may be due to increase in temperature of the air inside solar tunnel dryer. The results indicated that the atmospheric relative humidity was generally higher than that of the solar tunnel dryer and the difference was more than 40 per cent. It was reported that the relative humidity was high in the ambient air when compared with air inside the dryer [20].

Effect of temperature and relative humidity control system

The temperature and relative humidity inside solar tunnel dryer was automatically controlled using automatically controlled exhaust fans at chimneys. The set point for temperature and relative humidity was 60°C and 50% respectively for coconuts, which was fixed manually through computer programming. Whenever the temperature and relative humidity crossed the limit, the exhaust fan was automatically switched on and forced the exhaust air outside to control the temperature and relative humidity in permissible limit. This control system avoids fungal attack due to high relative humidity during initial drying hours and prevents evaporation of oil due to high temperature in final drying hours.

Drying characteristics

The drying characteristic curves of coconuts by open sun drying and solar tunnel drying are presented [Fig-3(a)], [Fig-3(b)] and [Fig-3(c)].

The moisture content versus drying time for coconuts in solar tunnel drying mode was presented in [Fig-3(a)], which showed that the moisture removal was nearly uniform during drying process with little variations. It was observed that the initial moisture removal was rapid with lower amount of moisture removal during the beginning and end of everyday and recorded a maximum value in the afternoon around 1:00 PM to 3:00 PM. The maximum moisture removal was recorded during morning of first day and afternoon of second day and it is estimated as 8.4 per cent 7.37 per cent respectively.

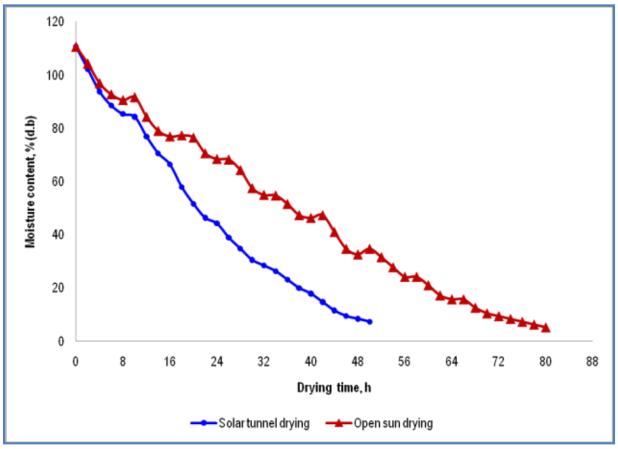

Fig-3(a) Moisture reduction curve for open sun drying and solar tunnel drying of coconuts

The curve for drying rate versus drying time in solar tunnel drying mode [Fig-3(b)], recorded three peak levels of drying during the total drying period of 49.5 hours. At the beginning of drying process, surface moisture was evaporated and the drying rate was high. Reduction was observed due to evaporation of free moisture migration from outer surface layer and gets reduced afterwards due to internal moisture migration from inner layer to surface. The drying rate decreased with an increase in the drying time. It was reported that the drying rate for coconut drying during initial drying period was high due to evaporation of surface moisture [21]. This confirmed with the results of the present study. The maximum drying rate of 0.042 g of moisture per g of dry matter per hour recorded during drying process and minimum drying rate was found to be 0.021 g of moisture per g of dry matter per hour.

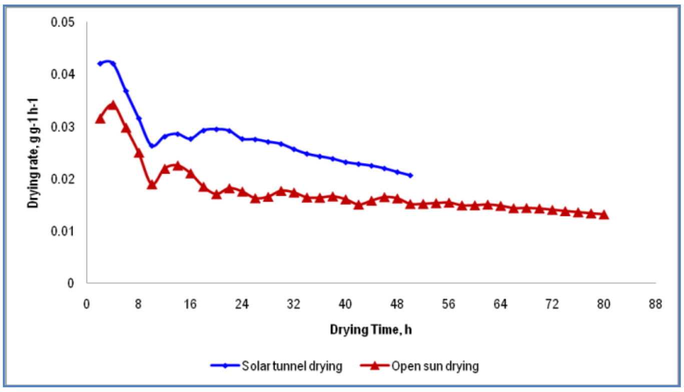

Fig-3(b) Drying rate curve for open sun drying and solar tunnel drying of coconuts

Curve of moisture ratio versus drying time for drying of coconuts in solar tunnel dryer is presented in [Fig-3(c)], which showed that the moisture ratio of coconuts reduced exponentially as the drying time increased. Drying was not uniform during entire drying period and recorded less quantum of moisture removal during beginning and end of everyday drying process and recorded maximum value in the afternoon around 1:00 PM to 3:00 PM.

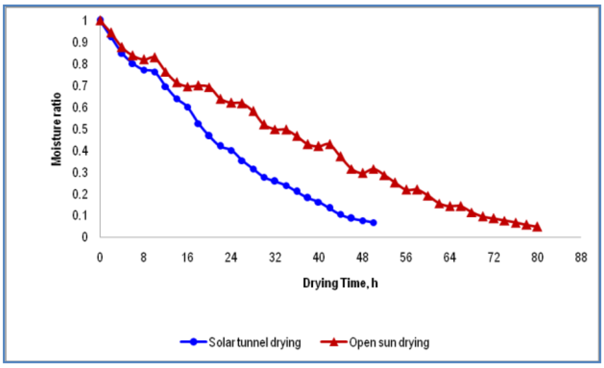

Fig-3(c) Moisture ratio for open sun drying and solar tunnel drying of coconuts

Conclusion

The semi cylindrical solar tunnel dryer covered with U.V. stabilized polyethylene sheet was designed with control system and fabricated. The field experiments on solar tunnel drying were conducted for drying coconuts as agro product and compared with open sun drying. The performance of solar tunnel dryer of 18.0 m x 3.75 m x 2.0 m dimension with 6.5 m^2 floor area was evaluated for drying coconuts as agro product. The maximum air temperature of 65 °C was obtained inside the solar tunnel dryer, which was controlled below 55 °C. The total drying time for drying coconuts was estimated to be 49.5 hours, whereas 80 hours in open sun drying mode. Moisture removal was uniform with drying rate having three peak levels throughout the drying period. The maximum drying rate of 0.042 g of moisture per g of dry matter per hour was obtained in solar tunnel drying mode whereas it is 0.034 g of moisture per g of dry matter per hour in open sun drying mode. Solar tunnel drying mode not only facilitates quick and uniform drying also protects from dust and insects, as the environmental condition is closed in solar tunnel dryer. Moreover, the control system avoids fungal attack and evaporation of oil content during initial and final drying hours respectively. This kind of control system motivates to integrate other renewable energy sources such as biomass, solar PV and biogas for drying in solar tunnel dryer during off sunshine hours.

Abbreviations

d.b	-	dry bulb
w.b	-	wet bulb
°C	-	degree Celsius

K - kelvin
kg - kilogram
g - gram
KJ - kilojoule
MJ - megajoule
h - hour
s - second
min - minute
W - Watt
m - metre
cm - centimetre
UV - ultraviolet
GI - galvanized iron
RTD - resistance temperature detector

Author Contributions

Corresponding Author [G Saravanapriya[1*]] and Author [R Mahendiran[2]] designed, developed, and installed the system and carried out the experimental trials and data analysis. Draft the manuscript and revised critically and approved the research paper for publication.

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Conflict of Interest: None declared

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