Study on Thermal Efficiency Enhancement in Solar Tunnel Drier

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***Abstract*— The interior structure of solar tunnel drier gets heated up as the UV rays from sun passes through it. As the material is partly opaque, the thermal energy gets trapped and it will not re-radiate. Solar driers are equipped, generally of small capacity and based rather on empirical and semi-empirical data than in theoretical designs. The majority of the numerous solar driers which are available are mainly used for drying various crops either for family or for small scale industrial production. Solar tunnel drier was developed based on greenhouse effect, which consists of a structure, enclosed by an UV stabilized sheets, which absorbs the solar energy and traps it because of its partly opaque property to long wave radiation. This helps in the increased temperature inside the drier than ambient temperature. A working model of solar tunnel drier was developed, where in the polyethylene plastic sheet was used as cladding material (for both single and double layer), for this study. Experiments were conducted on both the setups to study the increase in temperature inside of single layer and double layer solar tunnel drier with ambient temperature.**

Index Terms*— Solar tunnel drier, Thermal efficiency enhancement, Radiation, Natural convection drying

I. Introduction

Sun drying technique is one of the oldest and the most common practices of preservation of fruits, vegetables, and food without deterioration in the quality. Drying eatable agricultural food products not only prolong the storage life of the product, but also enhance the quality. However, the process is largely dependent on the weather and is very difficult during the rainy season. Moreover, the traditional method usually yields products with high microbial load. The exposure to wind and to unfavorable weather conditions results in great loss, through spoilage, lack of uniformity in the final product and development of undesirable flavor.

The sun drying practice of small-scale producers diminishes the quality of the commodities being dried. The practice allows dust, flies and microorganisms to feast on the products. Apart from its health hazards, the poor quality dried products fail quality standards and are unacceptable for export. Whereas,

many small-scale processors hardly meet the operation cost of commercial mechanical driers. Solar tunnel drier helps in advocating the aforementioned problems.

Solar tunnel drier is not a novel idea [1] and it is dated back centuries. Several experiments were carried out by researchers and still many researches are working on to improve the efficiency of the tunnel drier and utilize the maximum amount of available solar energy. Solar drier can be broadly classified into two types. I) Natural convection or passive drier and ii) Forced convection or active solar drier. F.K. Forson et al [2] and D.S. Lee et al [3] explains optimization technique for commercial scale crop drying. They also showed that passive solar drier method is the most attractive method for drying agricultural products. Choice of suitable dryer for appropriate application is most important. C.L. Hii et al [4] gave details about the fundamentals of solar dryer with applications. Different types of dryers with their applications are explained there. Based on the climatic changes of the drier location, choice is made between forced and natural convection drier.

Design of a tunnel drier is another important factors and the construction of the solar tunnel driers are done based on available land, quantity of agricultural products being used, climatic conditions etc. Generally walk-in type hemispherical drier is used for industrial purposes because of various advantages and better efficiency [5]. [6] to [9] explains about the various types of commercial solar tunnel driers for various crops and agricultural products.

Gauhar A. Mastekayeva et. al [10] studied the performance of a solar biomass hybrid tunnel drier for chilly drying and reported that 19.5 Kg of fresh chilly with an initial moisture content of 7.6% was dried to a final moisture content of 6.6% within 12 hours. Similarly, the moisture content of 21Kg of fresh harvested mushroom was reduced from 91.4% to 9.8% during

12 hours of drying. The result indicates that for both the products drying is faster, and is within 12 hours in normal sunny weather, against 2-3 days in solar tunnel operation and 3-5 days in open sun drying. J.H. McGuire [11] explains that air gap between two glass panel provides a solid thermal insulation and resists the heat transfer through convection.

In this paper, a miniature laboratory model of solar tunnel drier is constructed using cladding material, and tested for normal efficiency. A second layer of cladding material is built over the first layer with 50 mm air gap and 100mm air gap between them and the difference in efficiency is studied to know the effectiveness of thermal insulation because of the air gap between the two layers.

II. Materials and Methodology

A working model of solar tunnel drier was constructed using polyethylene as cladding material to carry out the study experiment. The solar drier has a convex shape roof made of 200 micron polyethylene sheet. The properties of the Polyethylene is shown in Table 1. The drier is set on a card board to make it mobile. It is provided with an inlet door to keep the drying materials and small vents are provided on the sides of the tunnel to achieve natural draft. The vents control the air inflow and outflow. Figure 1 and 2 shows the line diagram and the miniature model used for experimentation.

The movement of air through the vents, when the drier is placed in the path of airflow, brings about a thermo siphon effect which creates an updraft of solar heated air laden with moisture out of the drying chamber. The source of air flow is through natural Convection and it blows away the moist air out of the tunnel through vents.

Table 1: Properties of Polyethylene

Property	LDPE
Density	0.033 to 0.92 (lb/in³) (g/cm³)
Coefficient of linear thermal expansion	3 (x 10-5n./in./°F
Approx. Melting temperature	230 / 11 (°F / °C)
Max operating temperature	160 / 71 (°F / °C)
Glass transition temperature	-78 °C
Amorphous density at 25°C	0.855 g/cm^3
Crystalline density at 25°C	1.0 g/cm^3
Molecular weight of repeating unit	28.05g/mol

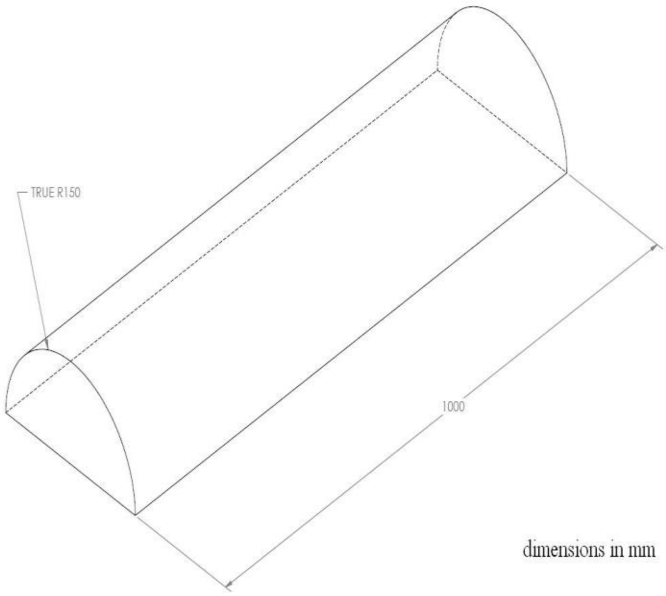

Figure 1: Line diagram of single layer hemispherical tunnel drier.

The size of the drier is determined as a function of the drying area needed per kilogram of fruits/vegetables. The drying temperature is established as a function of maximum limit of temperature of the fruit might hold. Since our model is for study purpose, the total base area of the drier is 0.3 m^2 with length 1 m and width 0.3 m. Bead strand is used to build the support structure. The structure is covered using the polyethylene sheet, and small air gap is provided to achieve natural draft. Figure 2 shows the constructed model of solar tunnel drier. The setup is placed over an insulation material to avoid the heat loss due to conduction.

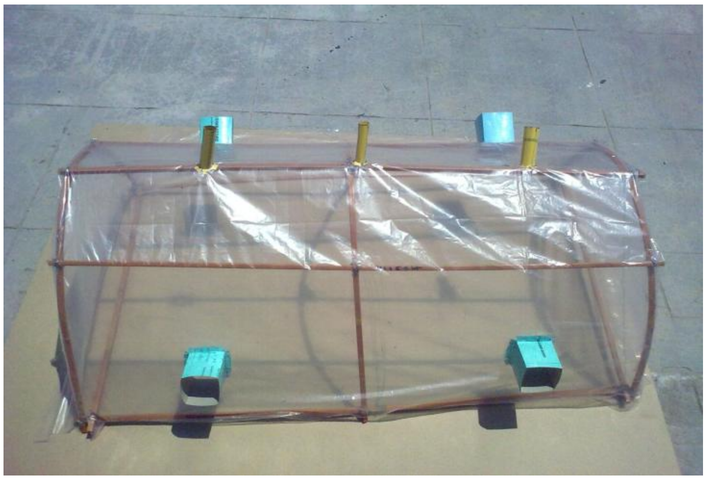

Figure a

Figure b
Figure 2: Miniature model of polyethylene cladding solar tunnel drier used for study a) single layer b) double layer cladding tunnel.

III. EXPERIMENTATION AND PROCEDURE

The experiments were conducted during March 2014 on hostel roof in Dr. Mahalingam College of Engineering and Technology, Pollachi. The orientation of the greenhouse type solar drier was kept in east-west facing direction during which the maximum solar incident radiation falls on the drier. The readings were taken for 8 hours of daytime starting from 10.30 in the morning till 6.15pm in the evening. Basically studies were on two phases, one with single layer and case two with double layers with dead air gap of 50 mm and 100mm to know the optimum gap between two layers. The main idea of this study is aimed at improving the thermal efficiency of the solar drier space with same setup with additional cladding material.

During the experimentation, various measuring devices were used to investigate the effects of the environment and operation parameters on the performance of the proposed solar tunnel drier. Measurements were taken every 1 hour during the operation period. The total incident solar radiation on the horizontal surface was measured using Solar Intensity meter and it gives direct cumulative readings of total global radiation. The instrument is powered and kept near the drier for a while. The digital meter directly shows the intensity of the solar radiation in W/m^2. Temperature, inside and outside the tunnel, is measured with the aid of Thermometer. The thermometer gauge consists of two types of thermometer to measure both the Wet Bulb Temperature (WBT) and Dry Bulb Temperature (DBT). Wet Bulb Temperature gauge consists of thermometer whose bulb is covered with wet cloth. The thermometer gauge is kept in the ambient atmosphere to attain steady state temperature and noted. The relative humidity of air was calculated from measured Wet Bulb and Dry Bulb temperature using a Psychometric chart. The velocity of air passing through the system and the wind velocity is measured using Thermo Anemometer. The speed range of anemometer is 0-20m/s. The instrument is placed in the direction of solar drier (east-west) and the digital gauge directly gives the wind velocity. Since the tunnel used here is for study purpose and the dimension being small, wind velocity inside the drier is neglected.

A. *Testing solar drier*

The experiment of single layer solar drier was conducted for 3 days to measure the temperature inside and outside the collector. During the experimentation, a small gap was provided for the free inflow of air inside the drier, since the study was based on natural convection or passive type drier. The vents help in achieving the natural draft of hot air inside the tunnel (Thermo syphon principle). Readings were taken at a regular interval starting from 10.30am in the morning till 6.15pm in the evening. Thermometer is used to take the temperature inside and outside the solar drier. Both WBT and DBT were noted. Solar intensity meter measures the solar radiation and anemometer measures the wind velocity. Every one hour, the temperature, solar intensity and wind velocity were measured. With WBT and DBT, the relative humidity can be obtained using Psychometric chart.

When the solar radiation falls on the polyethylene sheet, because of its transparency, it is transmitted inside the tunnel drier. The Ultra violet incident solar radiation as it pass through the polyethylene sheet, the wavelength of the solar radiation changes from UV rays to IR rays. As wavelength of IR rays are shorter, and due to the partly opaque property of the polyethylene sheet, the rays get trapped inside the drier and it is not reflected back.

IV. RESULT AND DISCUSSION

The experiments were carried out under the climatic conditions of Pollachi, Tamil Nadu during March 2014. First single cladding covered tunnel drier is tested and the readings are noted. Measurements were taken discretely at an interval of one hour starting from 10:30am in the morning and tabulated. From Table 2 readings it can be seen that the maximum difference in temperature is achieved during 2.30pm when the solar intensity is maximum.

Table 2: Tabulation of Ambient temperature, Drier temperature, Relative humidity and solar intensity with respect to time

Time	Ambient Temperature	Drier Temperature	Drier RH %	Solar Intensity
10.30	31.5	37	56	221
11:30	32.7	40.2	50	307
12:30	33.4	42.4	48	415
13:30	33.9	43.5	35	506
14:30	35	45	30	565
15:30	34.3	44	38	482
16:30	33.8	41.3	43	363
17:30	32.5	37.8	59	279

Similarly readings were taken on double glazing polyethylene solar tunnel drier with dead air space of 50mm and 100mm. Readings were taken from 10.30am in the morning till 6.15pm in the evening, on 20-3-2014 and 21-3-2014. The maximum temperature noted was 36 ºC at 14.30 when the solar intensity is 576 W/m^2. Table 3 and 4 shows the readings taken on 20-3-2014 and 21-3-2014 of double layer solar tunnel drier.

Table 3: Tabulation of Ambient temperature, drier temperature, relative humidity and solar intensity with respect to time on Double layer solar tunnel drier. Readings taken on 20-3-2014.

Time	Ambient Temperature	Drier Temperature	Drier RH %	Solar Intensity
10.30	32.5	38.5	55	243
11:30	34	41.3	48	326
12:30	34.4	43.8	46	443
13:30	35	45.9	34	538
14:30	36	52	29	578
15:30	35.3	47.4	37	494
16:30	34.8	44.1	43	382
17:30	33.5	40	50	294
18:15	31	35	60	87

Table 4: Tabulation of Ambient temperature, drier temperature, relative humidity and solar intensity with respect to time on Double layer solar tunnel drier (100 mm air gap). Readings taken on 21-3-2014.

Time	Ambient Temperature	Drier Temperature	Drier RH %	Solar Intensity
10.30	32.5	38	55	243
11:30	33.5	40.3	48	326
12:30	34.5	42.8	46	443
13:30	35.2	45	34	538
14:30	36.1	49.8	29	578
15:30	35.3	45.4	37	494
16:30	34.6	43.2	43	382
17:30	33.8	39	50	294
18:15	30.2	33.7	60	87

The dead air space with 50mm gap between two layers serves as an insulator for increasing the heat balance inside the drier area [11]. The maximum temperature achieved inside the drier was 52 ºC, which is 16 ºC greater than ambient air temperature.

From Figure 3 it is seen that maximum temperature of 45 ºC is achieved inside the single layer solar tunnel drier, when the ambient temperature and solar intensity is 35 ºC and 565 W/m2 (at 2.30pm).

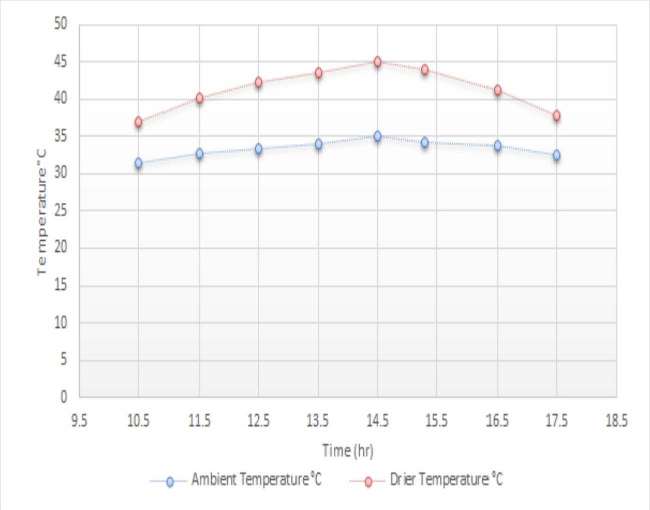

Figure 3: Variation of ambient temperature and drier temperature with respect to time.

From the results of temperature versus time graph shown in the figure 4 and 5, it is apparent that maximum air temperature inside the solar drier is 50mm dead air space was 52 ºC. The ambient temperature ranged from 30-36 ºC. The temperature rise above ambient air was in the range of 6-16 ºC. While the insulation gap of 100mm between two cladding coverings, the increase is temperature from its ambient is 13 ºC. Similarly at 2.30pm, the maximum temperature and solar intensity (578 W/m^2) is noticed. See Figure 6 for solar intensity variation with respect to time.

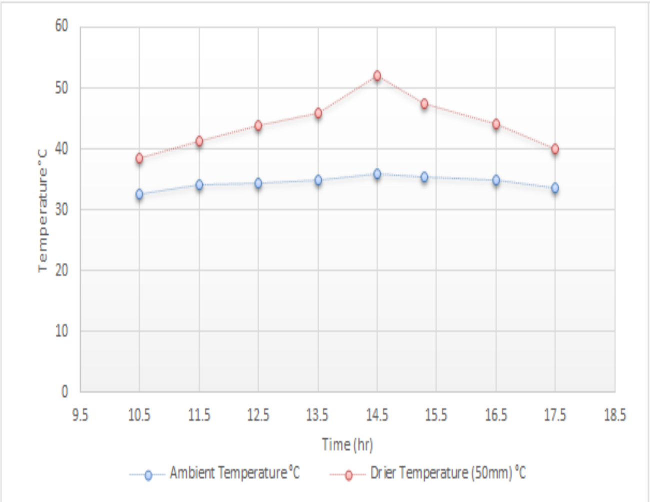

Figure 4: Variation of ambient temperature and drier temperature for 50mm air gap with respect to time on 20-3-2012

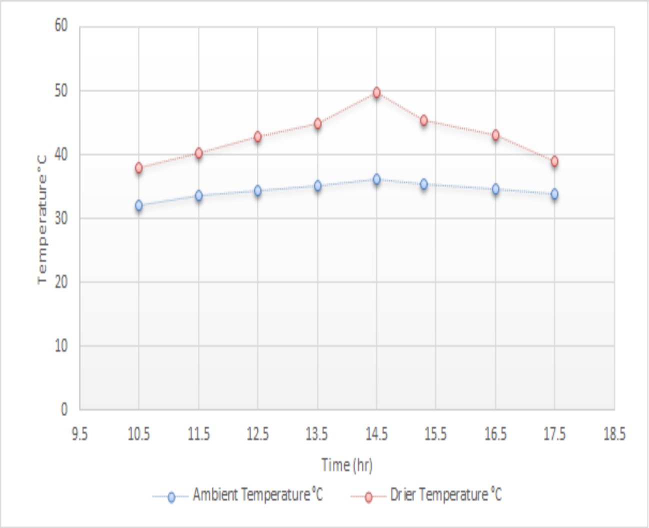

Figure 5: Variation of ambient temperature and drier temperature for 100mm air gap with respect to time on 21-3-2012

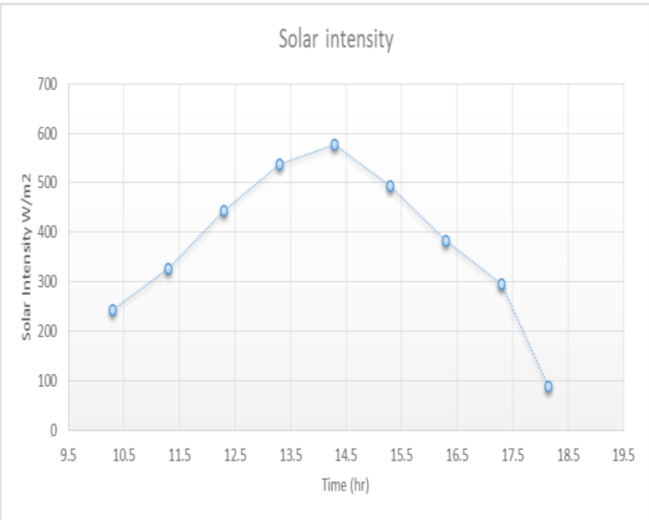

Figure 6: Solar intensity curve

Experimental results plot of double cladding in Figure 7 shows that the increase in temperature of solar drier of single layer cover was 10 °C, whereas the temperature rise of solar drier with 50mm dead air space was found to be 16°C whereas, 100mm insulation gap give 13 °C rise in temperature. The double layer covered solar drier with 50mm dead air space attained higher temperature rise of about 6°C than that of single layer covered solar drier. This confirmed the importance of dead air space in enhancing the thermal efficiency of the drier.

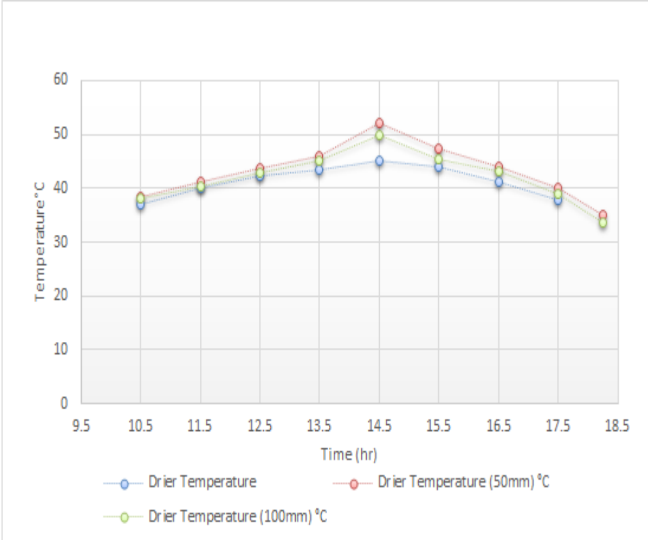

Figure 7: Comparison of drier temperature with single layer solar drier and double layer dead air space drier.

The air space between the layers acts as an insulator and also reduces the heat loss through radiation. The double glazing plastic covered greenhouse solar drier traps the solar energy in the form of thermal heat within the dead air space and reduces the convective heat loss. The fraction of trapped solar radiation will heat the enclosed air inside the drier space. Hence, the temperature inside the solar tunnel gets build up. Due to the reduced convective heat loss inside the double layer solar drier, there existed a temperature difference of about 16 °C.

V. CONCLUSION

Utilization of solar drying has been reported to be economical for drying of various high value crops. The present study is to determine the effect of two layers of cladding materials (UV stabilized polyethylene sheet) in enhancing the thermal efficiency of the system. A laboratory working model of solar drier of size 600mm wide and 1000mm long with 300mm maximum arc radius was constructed, with provision for fixing the second layer of cladding. Measurements were made during summer (March, 2014).

The constructed prototype showed a maximum temperature of 45 °C inside one layer cladding covered drier compared to 52°C when additional layer of cladding material was covered with thermal air gap of 50mm between the layers are allowed. The dead space between the layers prevented the convective and radiative heat loss. Because of low thermal conductivity of air, the air gap acts as a resistor for the emitted ray from the tunnel. The performance of the system is promising, showing a satisfactory increase in temperature of 13-16°C with increase in efficiency of about 8%. And also, comparing the increase in temperature inside the tunnel drier for both 50mm and 100mm air gap, 50mm air gap shows promising increase in temperature. If the gap between increased beyond 50mm, the temperature inside falls.

In the future, different kind of agricultural crops can be kept inside the experimental drier setup to note the time taken to dry completely. Difference in time can give the clear picture of the economic advantage of the drier. Also heat absorbing materials can be kept inside the drier to use the drier at off day light time.

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