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Design and Mathematical Modelling Of Mixed Mode Solar Dryer Applicable For Small Scale Application

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Abstract: **-- The new mixed mode solar dryer was designed and developed. As the open sun drying technique was time-consuming as well as less efficient, the natural convection solar dryer of mixed mode was designed and developed. The design and mathematical modelling of the two-parameter absorber plate outlet temperature and the relative humidity was carried out. The dryer was operated without any load inside it and operated for the two months. The average wind speed was measured to be 0.50m/s whereas the average solar insolation was 1200W/m2 received over the inclined plate. The designed value of the absorber plate was 2.0 m2.The drying chamber was made of plastic sheet in which spectrum of solar insolation which tends to discoloration of the food products or agricultural is prevented. The ambient temperature was observed to be 28°C averagely through the experiment. The results are in good agreement with the theoretical results and dryer will be operated with the different high moisture product in the future and performance evaluation can be done. The food items with high moisture content such as 80% - 90% (w.b.) can be reduced to a final moisture content of the 10% - 15% (w.b.) in less duration as compared to the open sun drying. Also, the dryer is made be locally and economically viable material.**

Keywords: Mixed mode solar dryer, Indirect mode solar dryer, Design of dryer, absorber plate outlet temperature, Relative humidity inside the dryer, dryer outlet temperature.

I. INTRODUCTION

In India post harvesting losses are more due to the improper treatment of agricultural products after their harvesting. To preserve the agricultural products and food items for the long duration of time they are being dry by the open sun drying method. Open sun drying method may tend to reabsorption of moisture in the food items during the cloudy condition and night which reduces the quality of the dried product (Chavda and Kumar, 2009) [1]. As shown in Figure 1 major disadvantage of the open sun drying method is time consuming drying process, cloudy and rainy weather condition can affect the drying process, drying process may not be uniform, requirement of large drying area, contamination of food items by excreta, dust, insects, birds.

Figure 1: Open sun drying

Many researchers had developed the solar dryers of different type but still there is scope for improving the efficiency for the existing available solar drying systems. Technically drying is the process of removing access water from the product to the standard required level for preservation of it for the long duration (V.Belessiotis and E. Delyannis, 2010)[2]. Solar dryer is the simple and easily adoptable technology by small and household communities, yet it is not commercialized as much.

II. DESIGN AND MATHEMATICAL MODELLING OF INDIRECT SOLAR DRYER

2.1 Design of the dryer

The mixed mode solar dryer in which the solar radiation incident over the food products which are kept inside the drying chamber. Hence it has advantage of both the direct as well as indirect solar dryer. S.Maiti et al designed and developed an indirect solar dryer for drying of food items. Whereas M.S.Sevada designed and developed the tunnel type dryer. Author suggested the proper design for the entire indirect solar dryer and collector area of the indirect solar dryer is estimated as the function of the quantity of the products to be dried.

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The design for the mixed mode solar dryer is as follows which helps in designing the absorber part of the mixed mode solar dryer. The main parameters which are considered for the design are collector area, drying chamber area, and moisture to be removed from the product [3].

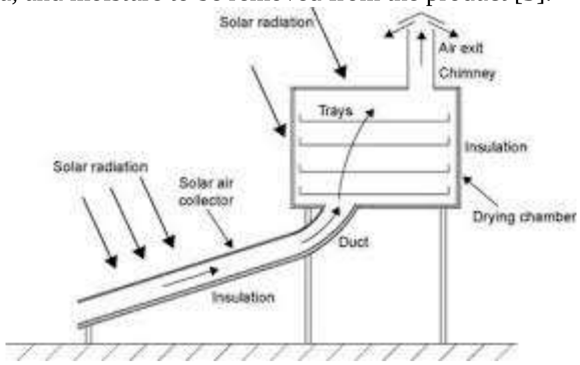

Figure 2: Schematic of Mixed mode solar dryer

Amount of the moisture to be removed from the product is given by:

$$M_w = \frac{M_L(X_i - X_f)}{(100 - X_f)} \quad (1)$$

The quantity of heat required to evaporate the moisture is given by:

$$Q = \frac{M_w h_{fg} \eta_{dr}}{\eta_{co}} \quad (2)$$

The collector area is calculated from the given formula:

$$A_c = \frac{10^{-3} Q}{t_d I_{ci} \eta_{co}} \quad (3)$$

Area of vent is calculated from the following expression:

$$A_{vent} = \frac{M_a}{(3600\, \rho_o\, w_{speed})} \quad (4)$$

The width of the air vent is given by:

$$W_v = A_v / L_v \quad (5)$$

The mixed mode solar dryer has the advantage of both the direct solar radiation as well as indirect heating of the food items by the hot air coming from the absorber plate.

The area of the drying chamber was determined by the following equation:

$$A_{drying} = \frac{10^{-3} Q}{t_d I_{ci} \eta_{do}}$$

The drying area is the function of the amount of the food items to be dried and the drying chamber efficiency as well as the solar insolation incident over the drying chamber.The length of the drying chamber is equal to the length of the air vent provided inside the absorber plate. The chimney was provided at the top of the drying chamber which has height of the 0.3 m and it is designed based on the temperature attained inside the drying chamber and the draft of the air produced. M.S.Sevada gives the complete design of the tunnel type dryer [13].

Where in X_i, X_f, h_{fg}, I_{ci}, W_s, ρ_o are the initial moisture content, final moisture content, latent heat of vaporization, insolation, wind speed and density of air respectively. The absorber material is made by wire mesh so as the air can collect more heat from the absorber plate [3].

2.2 Mathematical modelling of the hot air of collector dryer assembly

The temperature of the air at the outlet of the absorber plate is the main parameters which affect the performance of the dryer. The losses which are there over the absorber plate are mainly due to the convection losses and the radiation effect through the glass cover. The top loss heat transfer coefficient is the main parameter which needs to be reduced to get higher air outlet temperature. The total solar insolation incident on the absorber plate is sum of the heat collected by the air passing through it and heat loss from the absorber plate as well glass cover in the ambient. The heat loss at the bottom is due to the conduction which is considered where as for the properly insulated dryer the edge losses are neglected.

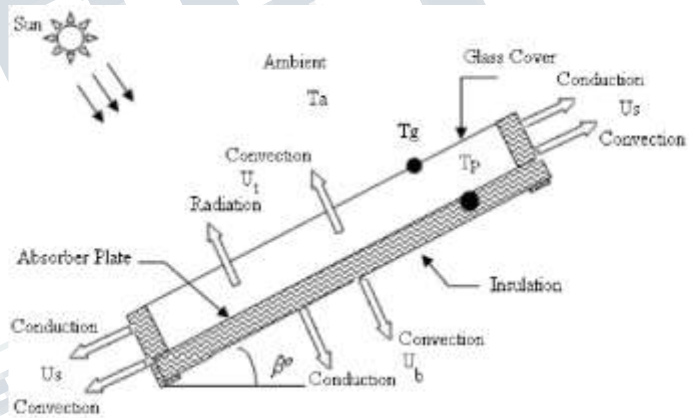

Figure: 3 Losses from the absorber plate

The losses which are taking place between the absorber plate and the glass cover are as shown in diagrammatically.

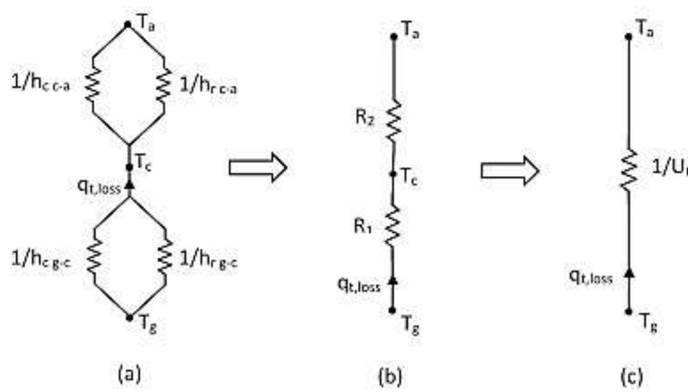

Figure: 4 Different thermal resistances to the air

Total Heat Incident on the collector = Heat carried/collected + rate of heat loss from the collector

$I_c\, A_c\, (\tau\alpha)_e = Q_u + Q_l$ (6)

τ = Transmissitvity =0.85

α = absorptivity =0.90

$T_{co} = T_{ci} + \frac{Ac\,[\,Ic\,(\tau\alpha)e -\, Ul(\,Tmp-Tamb\,)}{(m\,\dot{C}p)}$ (7)

Where U_l is the overall heat loss coefficient from the collector

$U_l = U_{top} + U_{bottom} + U_{edge}$ (8)

Bottom loss can be considered due to the conduction of the heat transfer which is given by the equation

$U_{bottom} = Kin / L_{in}$ (9)

2.3 Mathematical modelling of the relative humidity inside the dryer

The relative humidity inside the dryer mainly depends upon the temperature inside the drying chamber, relative humidity of the air entering inside the drying chamber, ambient temperature and equilibrium temperature inside the dryer, equilibrium relative humidity of the ambient. A material held for a long time at a fixed temperature and relative humidity will eventually reach a moisture content that is in equilibrium with the surrounding air. The relative humidity must be as low as possible inside the dryer for its effective working because the food products that are kept inside the dryer will eventually dry in less time as a result of the low relative humidity inside the dryer.

$ERH = exp\frac{-A}{M^B}$ (10)

In above equation the A and B are the model constants and ERH is the relative humidity inside the dryer.

2.4 Experimental procedure

The mixed mode type solar dryer was designed and tested in the no load condition for a two months. Absorber plate area was calculated to be $2.0m^2$ and the drying chamber area was found to be $2.9m^2$ by providing all the assumed and climatic data into the design equations. The K-type, Ni-Cr type thermocouple (accuracy of = ±0.01°C) was used to measure the plate temperature, hot air temperature, drying chamber outlet temperature, ambient temperature. The mass flow rate of air was determined by measuring the wind speed of the air which was measured by the thermo-anemometer. The relative humidity inside the dryer was measured by the thermohygro meter with accuracy of ±0.01%. The solar radiation was measured with the help of the PSP pyranometer.

III. RESULT AND DISCUSSION

3.1 Results for the relative humidity inside the dryer

The variation in the solar radiation during the experiment was also recorded. The maximum solar insolation on the inclined surface to be observed is 1150 W/m2 averagely, The relative humidity inside the dryer and ambient were measure simultaneously by keeping the hygrometer inside the dryer and the measured data were fed to the equation (10).The mixed mode solar dryer was operated under the no load condition in the clear sky condition and all the data were measure at every hour from the 09:00 am to 04:00pm. The plot 4(b) shows the relative humidity inside the dryer and is in the good agreement with the theoretical results, the relative humidity was in the excellent fit of R2 =0.947. Whereas plot 4(a) shows the comparison between the relative humidity inside the dryer and in the open atmosphere. It clearly designated that the relative humidity inside the dryer was very less as compared to the ambient this shows that the open drying of food items is less efficient than the solar drying inside the dryer.

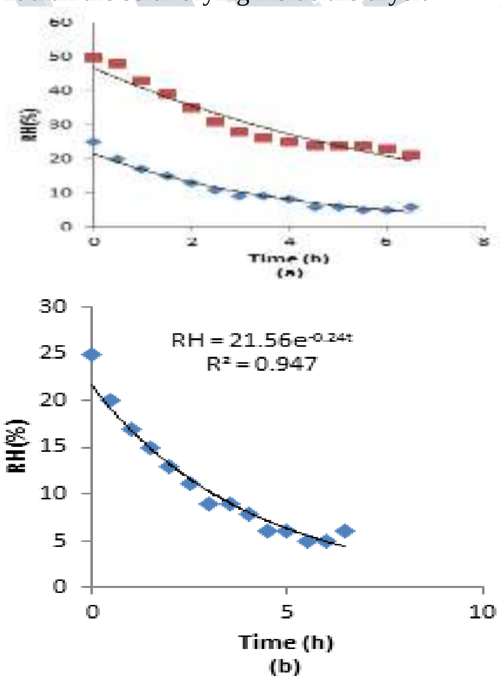

Figure: 4 (a) Comparison of relative humidity between open and inside dryer. (b) Relative humidity inside the dryer.

3.2 Results for absorber plate outlet temperature

The collector outlet temperature was measure at every hourly interval and fed to the equation (7). The average collector outlet temperature was measured to be 50°C. The plot 5(a) and (b), (c) shows the results of the collector outlet temperature vs. Solar radiation vs. Time which is in good agreement with the theoretical results with fit of R2 = 0.903, R2=0.927 and R2 =0.992. Also it is predicted that the absorber plate outlet temperature mainly depends upon the solar insolation, ambient temperature and mass flow rate of air inside the plate.

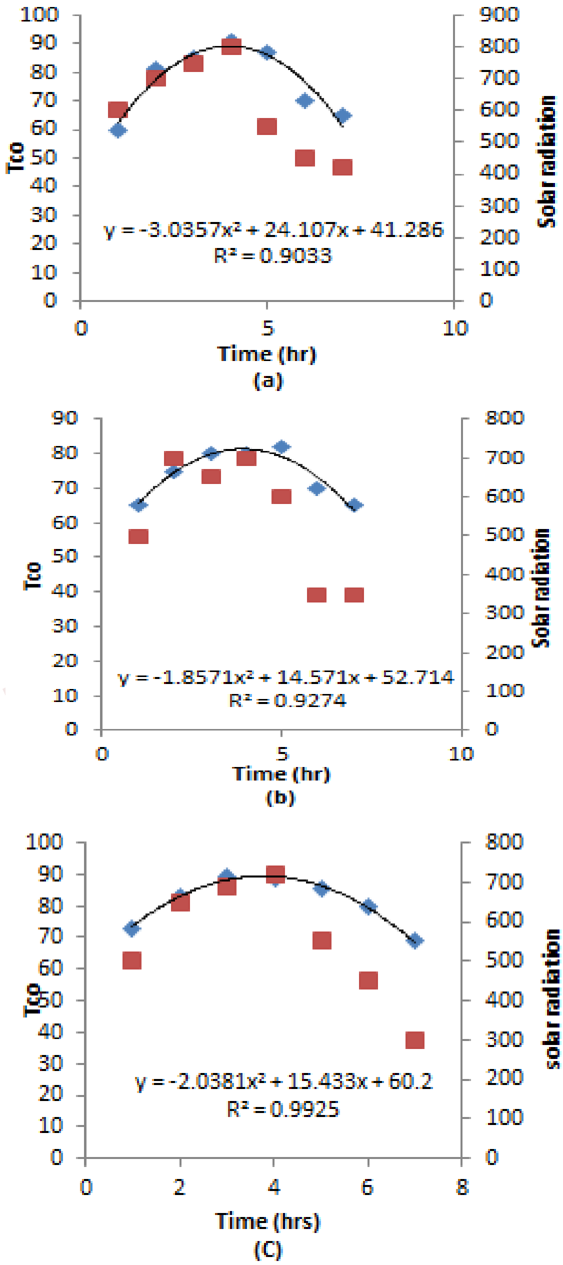

Figure: 5 modelling of absorber plate outlet temperatures (a, b, c)

IV. CONCLUSION

New and innovative design of the mixed mode and indirect solar dryer had been studied. Solar dryer was designed and tested for the few days in the no load conditions and the results were in the excellent fit. The relative humidity was observed inside the dryer to be very low as 5% and in the ambient it was observed to be 30% averagely. The absorber outlet temperature was observed to be 50°C averagely inside the dryer throughout the day. Since the solar radiation from the figure is low after noon the hot air temperature is still high. It was good in agreement with the theoretical data. It is concluded that the absorber outlet temperature should e as maximum a possible and the relative humidity inside the dryer should be minimum.

V. ACKNOWLEDGEMENT

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REFERENCES

[1] Chavda, T.V., Kumar, N., 2009. Solar dryers for high value agro products at SPRERI. Proceedings of the International Solar Food Processing Conference.

[2] Belessiotis, E.Delyannis, 2010. Solar Drying. Solar Energy 85, 1665-1691.

[3] Maiti S. , Patel P., Vyas K., Eswaran K., Ghosh P.K.,2011 .Performance evaluation of small scale indirect solar dryer with static reflector during non-summer months in the saurashtra region of western India. Solar Energy 85, 2686-2696.

[4] Lingayat A., Chandramohan V.P, Raju V.R.K, 2017. Design, development and performance evaluation of indirect type solar dryer for banana drying. Energy Procedia 109,409-416.

[5] Hegde V.N., Hosur V.S., Rathod S.K., Harsoor P.A., Narayana K.B., 2015.Design ,fabrication and performance evaluation of solar dryer for banana. Energy, sustainability and society.

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 3, Issue 2, February 2018

[6] Pangavhane D.R., Sawhney R.L., Sarsavadia P.N., 2002. Design, development and performance testing of new natural convection solar dryer. Energy27, 579-590.

[7] Banout J., Ehl P., Havlik J., Lojka B., Polesny Z.,Verner V.,201. Design and performance evaluation of a double pass solar drier for drying of red chilli. Solar Energy 85,506-515.

[8] Sreekumar A., Manikantan P.E., Vijayakumar K.P., 2008. Performance of indirect solar cabinet dryer. Energy conservation and management49, 1388-1395.

[9]El-Sebaii,A.A.,ShalabyS.M, 2013Experimental investigation of an indirect-mode forced convection solar dryer for drying thymus and mint 74,109-116.

[10] Bala.B.K., Janjai .S, 2005. Solar drying of fish (Bombay duck) using solar tunnel dryer. International energy 6.

[11] Kituu G.M. Shitanda D. , Kanali C.L. , Mailutha J.T. , Njoroge C.K. , Wainaina J.K. , Silayo V.K.,2010 .Thin layer drying model for simulating the drying of Tilapia fish (Oreochromis niloticus) in a solar tunnel dryer, Journal of food engineering 98,325-331.

[12] Forson, F.K., Nazha, M.A.A., Akuffo, F.O., Rajakaruna, H., 2007. Design of mixed-mode natural convection solar crop dryers: Application of principles and rules of thumb. Renewable Energy 32, 2306–2319.

[13] Sevada M.S., 2012. Design and development of walk-in type hemicylindrical solar tunnel dryer for industrial use. ISRN

[14] Sukhatme, S.P., Nayak, J.K., 2008. Solar Energy: Prinicples of Thermal Collection and Storage, 3rd Ed. Tata McGraw-Hill Publishing Company Limited, New Delhi, India.