PERFORMANCE EVALUATION OF A MIXED MODE SOLAR DRYER

[1]Wilma Julius M, [2]Dr. M. Sathyendra Kumar
[1]PG Student, [2]Professor
[1]Department of Electrical and Electronics Engineering
[1]NMAM Institute of Technology, Nitte, Udupi District, Karnataka, India

***Abstract* -In this paper a mixed mode dryer has been designed and developed by using the available materials in the market. Comparison between the natural convection and the forced convection solar dryer were studied to the solar collector area of 0.4 m^2 and the dryer area of 0.2 m^2 for the collector efficiency, dryer efficiency, moisture loss and time of drying. 80% moisture of fresh grapes was reduced to 15% for dry grapes with an average global radiation of 850w/m^2. The average temperature of the collector and dryer chamber were noted for Nitte climatic condition.**

***Keywords*—Mixed Mode Solar Dryer, Air heater, Drying chamber, Moisture Loss, Dryer and Collector Efficiency.**

I. Introduction

Drying of food products for preservation provides space for longer storage and easy transportation due to moisture removal by simultaneous heat and mass transfer [1]. Products like fruits and vegetables are dried at 45–60 °C for superior Quality [2]. Mainly drying systems are classified into low and high temperature dryers according to the operating temperatures. Low temperature dryers help for long term storage [3]. Whenever fast drying is required high temperature dryers are used with different heat sources like electricity and fossil fuels.

A renewable, clean and freely available alternative energy is the solar energy. Solar heat is used for the drying process which is termed as solar drying. To prevent the decay and spoilage of food products the moisture is removed at a suitable temperature [4]. Based on the food products and the water content present in them suitable design and sizes of the solar dryers are available. The main types in them are categorised as direct, indirect and mixed mode solar dryers [5][6].

i. Open sun drying:

The product that has to be dried is placed directly under the sun to achieve drying.

ii. Direct solar drying:

Products to be dries are placed in a fabricated transparent upper cover box with the side walls. The heat is absorbed inside the chamber and the moisture is evaporated by natural circulation of air.

iii. Indirect solar drying:

Mainly consists of two parts solar air heater and drying chamber. The heated air is ducted to the drying chamber.

iv. Mixed Mode solar drying:

It is the combination of both direct and indirect solar dryers, that is solar radiations directly incident on product and also the heated air from solar collector is passed to the drying chamber [7].

Onigbogi I.O, Sobowale, S. S and Ezekoma, O.S investigates and states that less attention is required for the product inside the dryer as it is protected from bird attack and rain compared to the open sun drying. And also easy monitoring less capital cost were the main advantages [8].

Shobhana Singh and Subodh Kumar 2012 studied on a mixed mode solar dryer and revealed that the mixed mode dryer performs better than an indirect dryer in terms of effectiveness [9].

Varun 2002 states that a fabricated mixed mode solar dryer combined with PV module for better air circulation avoids the disadvantages like losses of colour and flavours and also the microbial contaminations [10].

The overall strategy is to develop, design and fabricate the mixed mode solar dryer using indigenous materials to assess their efficiency in drying crops which provides an optimum temperature for efficient drying of the crops. The scope of the work consists of design calculations such as Declination angle, Optimum collector slope (β) Collector efficiency (η) Dryer efficiency (ηd) Moisture loss (ML) etc. of mixed mode dryer which consists of air heater and dryer chamber.

II. DESIGN CALCULATIONS

The design calculation includes [11]:

i. Collector Inclination (β)

$$\beta = \emptyset + \delta \quad (1)$$

Where, Ø = Latitude Angle
δ = Declination Angle

ii. Collector efficiency (η)

$$\eta = \frac{\rho V C p \Delta T}{A I g} \quad (2)$$

Where, ρ = Density of air (kg/m^3),
V = Volumetric flow rate (m^3/s)
Cp = Specific heat capacity of air at constant pressure (J/kg K)
Δ = Temperature elevation
A = Effective area of the collector facing the sun (m^3)
Ig = Insolation on the collector,

iii. Dryer efficiency (ηd)

$$\eta d = \frac{ML}{IgAt} \quad (3)$$

Where, L = latent heat of vaporization of water(J/kg)
M = Mass of the crop
t = time of drying.

iv. Heat energy Q needed for crop drying at moderate temperature

$$Q = MwL = \rho CpV(Ta - Tb) \quad (4)$$

Where, L = latent heat of vaporization of water(J/kg)
Mw = mass of crop before drying
ρ = density of water

Ta = ambient temperature

Tb = dryer temperature

v. Moisture content (M.C.)

$$MC(\%) = \frac{Mi - Mf}{Mi} \times 100 \quad (5)$$

Where, Mi = mass of sample before drying

Mf = mass of sample after drying

vi. Moisture loss (ML)

$$ML = Mi - Mf \quad (6)$$

Where, Mi = Mass of the sample before drying

Mf = Mass of the sample after drying

III. EXPERIMENTAL SETUP

A Mixed Mode Solar Dryer is constructed using cheap and readily available materials from the market. Fig 1 shows the dryer with solar collector and a drying chamber with a single drying tray [12].

i. Solar Collector or Air Heater

This heat absorber is a rectangular box constructed using half inch plywood sheet which enclosed of 1mm thick aluminium sheet which coated with a black paint. This assembly is closed by a 4mm transparent glass cover which has the transmittance above 0.7 for wavelength 0.2 – 2.0 micrometer and opaque to wavelength greater than 4.5 micrometer. The effective area of the collector is $0.4m^2$. One end of the collector is covered by mesh and the other end is let to the drying chamber.

ii. Drying Chamber

This chamber is fabricated using half inch plywood to withstand the atmospheric attacks. A vent is provided at the upper end for the convectional air flow through dryer. Doors are provided at the back for smooth operation of the drying racks. The roof is covered with a transparent glass sheet of 4mm thickness. The effective area of the dryer is $0.2m^2$

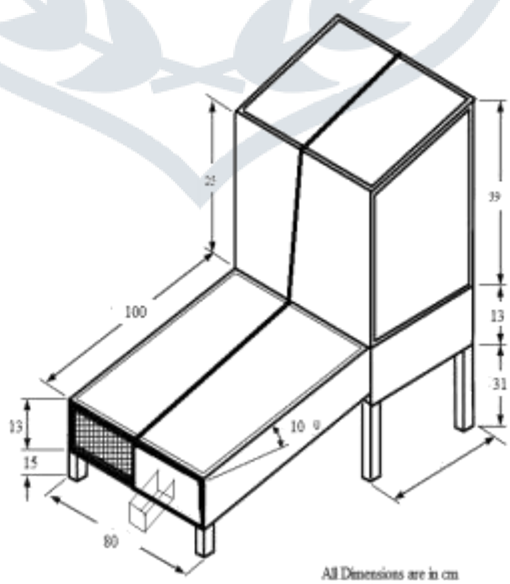

Fig 1 Drawing of a Mixed Mode Dryer

iii. Drying trays

Drying chamber consists of drying trays which are layers of chicken wire mesh with open structure which allows air to pass between the food items.

iv. Orientation of collector

The solar collector is tilted and oriented in such a way that it always receives maximum radiation. In northern hemisphere the orientation is due south and tilted 10º to the horizontal which is the best recommendation for stationary absorber. Table 1 shows the dimensions and specifications of dryer.

v. Operation of dryer

Fig 2 shows the mixed mode solar dryer. The dryer is a stationary system with no moving parts.

When the sun rays falls on the fabricated aluminum sheets of the collector the temperature of the sheet increases which in turn increases the temperature of the air surrounding it. The heated air is then passed to the drying chamber where the products to be dried are placed on the drying racks. A fan is induced in forced convection in which a duct is provided, which takes away the moisture present on the skin of crop. The hot air then escapes through the vent provided at the top of the drying chamber. Initial mass and the final mass of the crops after drying are noted. Temperature of the collector, drying chamber and global radiation are taken hourly

COMPONENTS	PARMETERS	DIMENSIONS
AIR HEATER or SOLAR COLLECTOR	Length x Width x Height Outer Box Covering Thickness of sheet Top Glass Covering Collector inclination Air Gap	100 x 80 x 13 cm^3 ½ inch plywood Al sheet of 1.2mm coated with black paint 4mm 10º 2cm
DRYING CHAMBER	Length x Width x Height Outer Box Covering Top Glass Covering Stainless steel mesh tray	50 x 80 x 25 cm^3 ½ inch plywood 4mm 50 x 30 cm^2
FAN	12v DC, 0.15A Flow rate–0.0151 m^3/min	120 x 120 x 38 mm^3
THERMOCOUPLE	K – Type (Chromel – Alumel)	(-10 – 1400) ºC

Table 2 Specifications of the dryer

Fig 2 Mixed Mode Solar Dryer

IV. RESULT AND DISCUSSION

In the month of February and March between 10AM to 5PM tests were conducted to analyse the performance of mixed mode dryer. Various values of temperature and global radiations were recorded and evaluated to different load densities of grapes at the Nitte climatic condition which is located at 13.18º latitude and 75.68 º longitudes.

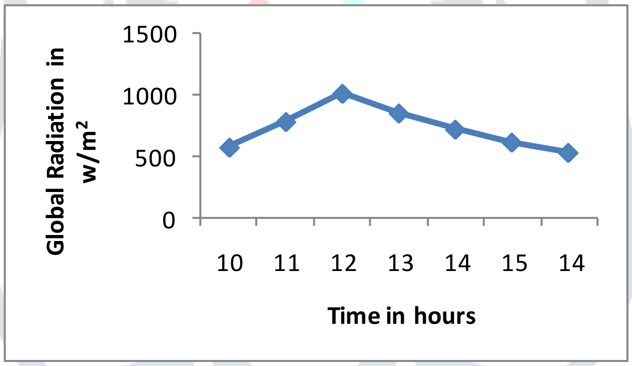

Fig 3 Global radiation Vs Time

Graph 3 shows the hourly variation of global radiation at Nitte (13.18º, 75.68º) climatic condition. Radiations were intense during 12PM and recorded 850w/m^2 for the month of February. Similar observations were made by Ahmed Abed Gatea [11].

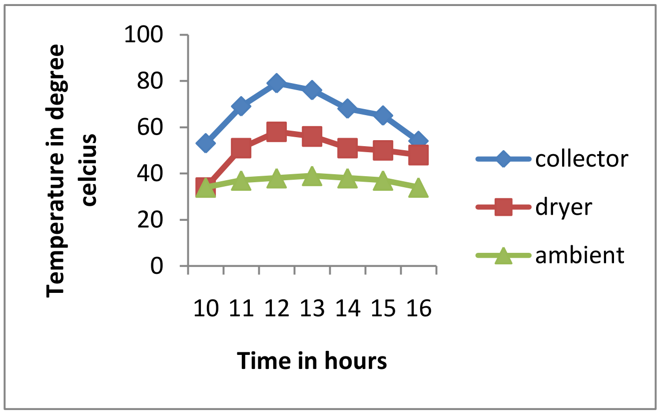

Fig 4 Temperatures Vs Time (Natural)

Graph 4 and 5 shows hourly variation of collector, dryer and ambient temperature for the natural and forced convection. It is observed that the maximum dryer temperature of natural and forced convection is 58ºC and 65ºC respectively and also the collector temperatures were 79ºC for natural convection and 90ºC for forced convection for which the ambient temperature was 38ºC. Similar observations were made by Onigbogi I.O, Sobowale, S. S and Ezekoma, O.S [8].

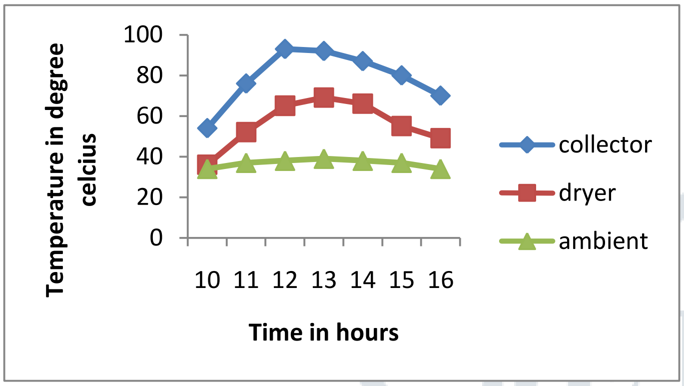

Fig 5 Temperature Vs Time (Forced)

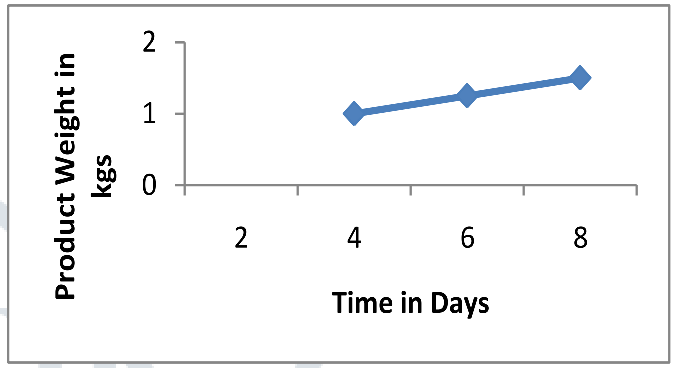

Fig 6 Weight Vs Time

Graph 6 shows the effect of load density on the time of drying. The dryer was tested for various kilograms of grapes (1kg, 1.25kg, 1.5kg) for which the drying time increased as the load density increased. It is observed that 1000 grams is reduced to 235 grams in 4 days.

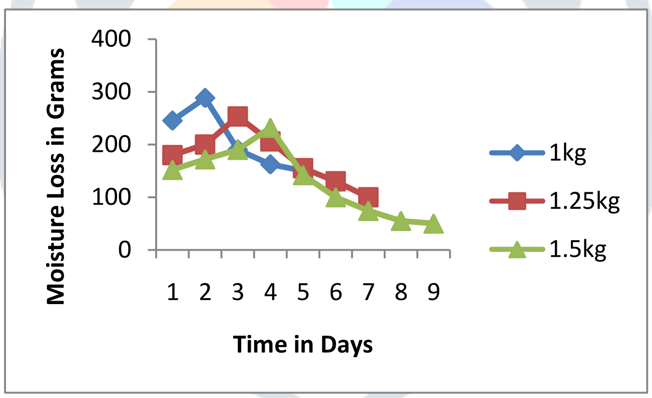

Fig 7 Moisture Loss Vs Time (Natural)

Graph 7 and 8 shows the moisture loss in grams for natural and forced convection variation to different days. Fresh grape contains 80% of water content, it is reduced to 15% in order to make it a dry grape. It is observed that the moisture loss in natural convection is low at initial stages, gradually increases with time, reaches maximum and then reduces. In forced convection the moisture loss rate is more compared to natural convection. 1000 grams were reduced to 235 grams in 4 days by forced convection where as 5 days by natural convection. Similar Observations were made by Ahmed Abed Gatea [11].

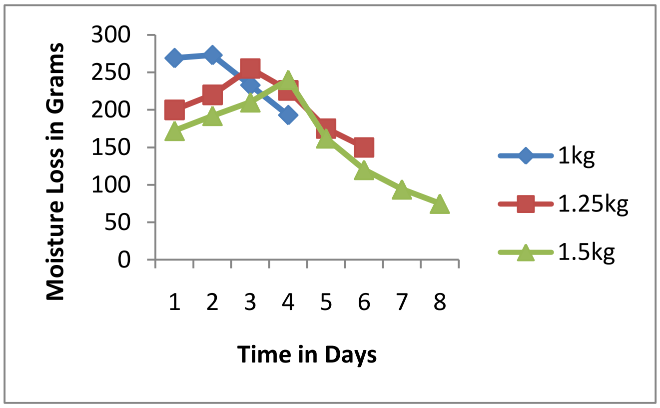

Fig 8 Moisture Loss Vs Time (Forced)

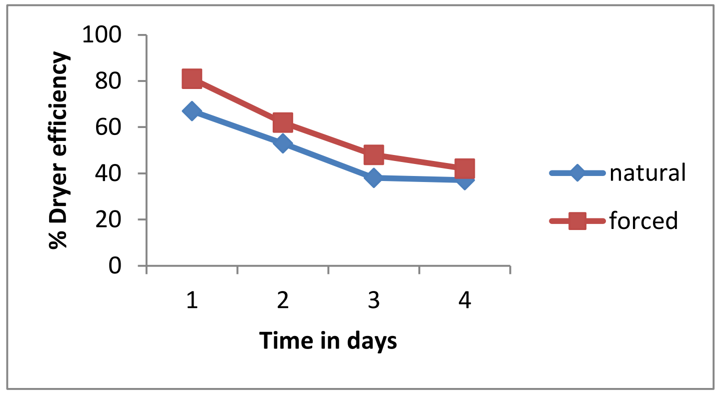

Fig 9 Dryer efficiency Vs time

Fig 9 shows the variation of drying efficiencies of natural and forced convection with time. The drying efficiencies of natural and forced convection are 67% and 80% respectively. It is observed that the efficiency is increased by 19% when compared with the natural convection. Similar observations were made by Chandrakumar B Pardhi and Jiwanlal L Bhagoria [13].

v. Conclusions

i. The maximum drying temperature obtained for the natural and forced convection is 58ºC and 65ºC respectively for ambient temperature of 39ºC.
ii. Drying air temperature was the main controlling factor which reduced the moisture content to 15% from 80% (dry basis).
iii. Drying time mainly depends on solar radiation intensity, relative humidity, wind speed and the ambient temperature.
iv. Using forced convection method 1000 grams was reduced to 235 grams in 4 days with average radiation intensity of 850w/m^2.
v. The efficiency of the natural convection is 67% and forced convection is 80%. Hence efficiency has been increased by 19%.
vi. The drying rate of grapes inside the dryer is around 0.256 kg/day where as for open sun drying it is 0.09 kg/day. Hence the performance is better in dryer and quality protected from dust and insects.

ACKNOWLEDGMENT

The authors would like to thank the management of Nitte Education Trust and Dr. Niranjan N. Chiplunkar, Principal–NMAMIT, Vice Principals Dr. Shrinivasa Rao B.R. and Dr. I. Ramesh Mithanthaya and HOD, Electrical and Electronics Engineering, NMAM Institute of Technology for encouraging the research work.

REFERENCES

[1] El-Sebaii A.A. and S.M. Shalaby (2012).Solar drying of agricultural products: A review, Renewable and Sustainable Energy Reviews 16, 37-43.

[2] 2. Lalit M. B., S. Satya and S.N. Naik (2012). Solar dryer with thermal energy storage systems for drying agricultural food products: A review, Renewable and Sustainable Energy Reviews 14, 2298–2314.

[3] 3. Ekechukwu O.V., (1999). Review of solar-energy drying systems I: an overview of drying principles and theory Energy Conversion & Management 40, 593-613.

[4] 4. Ajay C., K.S. Orsunil and D.P. Deepak (2009); Design of Solar Dryer with Turboventilator and Fireplace. www.solarfood.org/solarfood/..../solarfood

[5] 5. Atul S., C.R. Chen and V.L. Nguyen (2009). Solar-energy drying systems: A review, Renewable and Sustainable Energy Reviews 13, 1185–1210.

[6] 6. Fudholi A, K. Sopian, M.H. Ruslan, M.A. Alghoul and M.Y. Sulaiman (2010). Review of solar dryers for agricultural and marine products, Renewable and Sustainable Energy Reviews 14, 1–30.

[7] BABAGANA GUTTI, SILAS KIMAN and AHMED M. MURTALA Volume 2, Number 1: 31-38, July, 2012

[8] Onigbogi I.O, Sobowale, S. S and Ezekoma, O.S : DESIGN, CONSTRUCTION AND EVALUATION OF A SMALL SCALE SOLAR DRYER Volume 4, June 2012.

[9] Shobhana Singh and Subodh Kumar : Comparative Thermal Performance Study of Indirect and Mixed-mode Solar Dryers Dec 2012.

[10] Varun : Performance Evaluation of Solar Crop Dryer Integrated with Solar Air Heater – 2012

[11] Ahmed Abed Gatea Journal of Agricultural Biotechnology and Sustainable Development Vol. 3(4) pp. 65-71, April 2011.

[12] Nagarajan S, Prem kumar M- Analysis of thermal performance in solar dryer, 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 3 Ver. II (May- Jun. 2014), PP 71-74.

[13] Chandrakumar B Pardhi and Jiwanlal L Bhagoria- Development and performance evaluation of mixed-mode solar dryer with forced convection *International Journal of Energy and Environmental Engg 2013, 4:23* doi:10.1186/2251-6832-4-23.