International Journal of Advanced Technology in Engineering and Science
Vol. No. 06, Issue No. 08, August 2018
www.ijates.com
ijates
ISSN 2348 - 7550

Mathematical Modeling of Green-House Type Solar Tunnel Dryer for Drying of Grapes

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Abstract

Sun the very reason for life on Earth is also an enormous supplier of clean energy to our planet. For long from the primitive age until now, we have been relying on the solar rays for crop cultivation, preservation and processing.

Solar desiccation has always been used to desiccate cereal crops and fruits. With the advent of technology and our understanding to access solar energy we have started employing it efficiently to our requirement of preserving crops and fruits.

Open drying had been a time consuming and a low-quality affair. The improved green-house dryer kinds scores above above mentioned limitations of open drying.

The most important objective of this experimental study was to represents the performance of green-house type solar tunnel dryer to dry non-chemically treated grapes. Grapes were purchased from the Lucknow (India) local market for study, Green-house type solar tunnel dryer was installed on an agriculture land at Dyaram Purwa, Chinat Lucknow (India). During the experiment, average temperature inside the green-house type solar dryer rises from 18□C to 20□C above the ambient temperature.

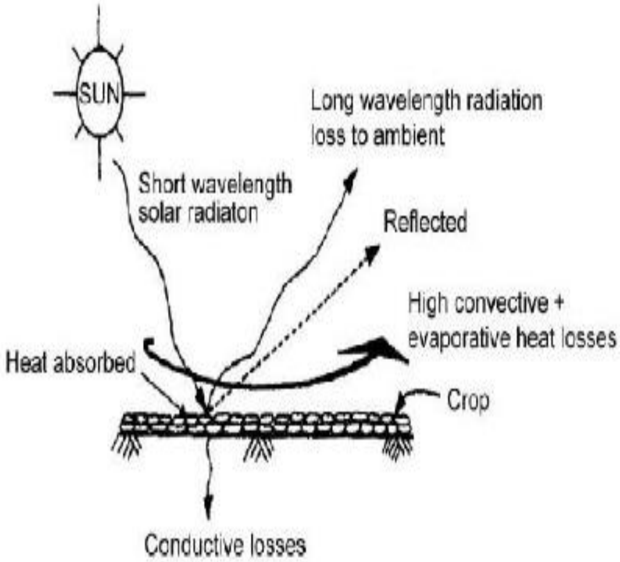
Green-house type solar tunnel dryer was installed with the dimensions of 10 ft* 6 ft* 8 ft, with the capacity of 48 kg. Grapes moisture content was reduced from 85% (wb) to 16% (wb) moisture content within seven days. Residential green-house type solar tunnel dryer was working between from 50□C to 68□C temperatures.

Index Terms— Moisture content, Solar Energy, Solar Tunnel dryer, Temperature.

I. INTRODUCTION

Today, the demand for energy is rising steeply, and it is an import factor for the life cycle. [1] Energy is available in nature in different forms like gase, coal and oil etc, each of which is perishable and polluting in nature, but solar energy is totally free and non-polluting. Solar energy is an imperishable renewable energy [2] which not only provides heat but can also be tapped for electricity production. Now a day's most of the countries are generating power and energy by means of non-renewable energy resources like, hydro-power plant, thermal power plant and gas power plant etc. which are a cause of high pollution [3]. Disposals from power generation plant are harmful for mankind and environment [4].

Shape of sun is perfectly sphere and the diameter is 1.39 x 109m. Sun consists of high intensity hot plasma. The rays of sun reach on earth surface in an average 8 minutes and 19 sec. The distance of earth from sun is 1.5 x 1011 m. The sun has an effective blackbody temperature of 5762 K [5]. Temperature of centre region of sun is 8 x 106 K to 40 x 106 K. There is a fusion reaction in which hydrogen is converted in to helium. The sun's total [6] energy output is 3.8 x 1020 which is equal to 63 MW/m2 of the sun's surface [7]. This energy radiates outwards in all directions. Only a tiny fraction, 1.7 x 1014 kW, of the total radiation emitted is intercepted by the earth [8]. However, even with this small fraction, it is estimated that 30 min of solar radiation falling on earth is equivalent to the demand of world energy for one year.



II. **METHOD AND MATERIALS**

A. Open Sun Drying

Open drying is the vastly used technique used in India and around the world. Its advantage is that it is applied in its raw form without need of any major investment, but the associated drawbacks such as loss due to animal attack, loss due to weather, adulteration by dust, long drying duration etc. has created the need for a better technique of utilizing sun's energy for drying crops. Figure 1 describes the principle of open sun drying.

B. Solar Dryer

Systematic diagram of green-house type STD is shown in figure: 2. This solar tunnel dryer is a walking type in unloading condition only, once it is loaded then it has no space for walking. Base of the dryer is

RCC and structure like hemi-cylindrical made of mild steel is covered with a UV stabilized semi-transparent polyethylene sheet of 200 microns. The base of the solar dryer was painted black.

In this experiment, we used a small solar collector in the base of the solar dryer. About 60 ft Galvanized Pipe was used. The area equivalents to a half diameter of pipes were holed with the help of hand drilling machine. Un-drilled face of the pipe is placed on the ground and an RCC base is prepared for the solar dryer.

Hot air flows through these pipes with the help of a centrifugal pump. Hot air flows in the base of solar dryer below the RCC layer, due to this the floor temperature rises 2 to 3 times as compared to another method.

A humidity control fan is installed in the end frame. Joints in the frame are permanent & semi-permanent are used for fabrication of structure.

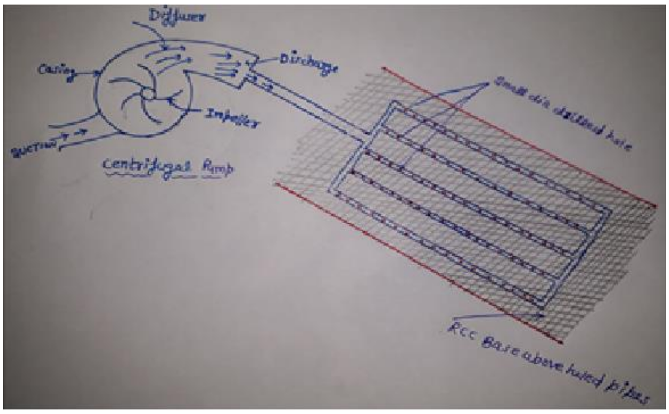


Fig. 3 Schematic diagram of galvanized piping system used for flows of hot air to solar dryer RCC base

TABLE I - DIMENSIONS OF SOLAR TUNNEL DRYER

Description	Dimensions
Arc length – Hemi Cylindrical	06.52 ft
ST dryer Length	10.00 ft
ST dryer width	06.00 ft
North wall height	05.00 ft
Total chimney in STD	03 nos
Chimney height	01.05 ft
Thickness of UV plastic sheet	200µ

Along the Green house type STD length, a slope of 2° to 3° was provided. All necessary provisions were made to reduce the heat loss from the RCC base and north side STD wall [9]. Three chimneys were installed on the top of the solar dryer at equivalent distance to maintain natural draft inside the STD, due to these chimneys buoyancy force was increased to addition of air flow in STD. This buoyancy force is directly proportional to the difference between the mean air density within the chimney and the density of outside air [10]. The product is placed on two tables, every table has two trays the capacity of the dryer was approx. 48 kilograms. This green house type solar tunnel dryer was designed for Indian weather conditions.

C. *Experiment*

The grapes were purchased from local market. Grapes selection for experiment was not easy, so uniform sizes of grapes were selected for study and other size of grapes was rejected. Selected grapes were separated from the bunch and these grapes were washed with normal water, before placing the grapes inside the solar dryer no chemical is treated. Grapes that have skin injuries were rejected. Thermocouples were placed at four different locations to record the temperature inside the STD. On the wet basis calculation was made for reduction in moisture every day.

Fig. 4 Sample of Grapes before washing and without separating from bunch

Fig. 5 Sample of Grapes after drying (Final Product)

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ISSN 2348 - 7550

D. Mathematical Modeling of solar Tunnel dryer

In last three to five years so many experiments were performed on solar dryer. The solar drying curves obtained were fitted with eight different moisture ratio equations (Table II). MR (Moisture ratio) was analysed and calculated by (M/M0) in place of (M - Me)/ (Mo - Me) cause of RH of the drying air continuously fluctuated in solar drying [11]. The correlation coefficient (r) was one of the primary criteria for selection of best equation in the account for variation in the solar drying curves of the dried samples. In addition to (r), reduced χ-square as the mean square of the deviations between the experimental and calculated values for the models was used to determine the goodness of the fit. The lower the values of the reduced χ-square, the better the goodness of the fit, and these were analysed and calculated as:

TABLE II

MATHEMATICAL MODELS APPLIED TO SOLAR DRYING CURVES

SNo	Model Name	Model
	Lewis model	
	Page model	
	Henderson-Pabis model	
	Logarithmic model	
	Two term model	
	Modified Henderson-Pabis model	
	Wang and Singh	

=

Where

MRexp,i = ith experimental moisture ratio,

MRpre,i = ith predicted moisture ratio,

N = number of observations and n the number of constants

III. RESULT AND DISCUSSION

A. No Load Test of Solar Dryer

The drying test (no load test) was conducted in December 2016 & April 2017. To analyse the temperature behaviours inside the tunnel dryer, temperature was monitored at selected point. Here, temperature and humidity behaviours of experimental days were discussed and presented with suitable graph.

Fig.6 Average variations in temperature during no load test in Solar Tunnel Dryer (Dec.16)

Fig.7 Average variation in relative humidity during no load test Solar Tunnel Dryer (Dec.16)

Fig.8 Average variation in temperature during no load test in Solar Tunnel Dryer (April 2017)

Fig.9 Average variation in relative humidity during no load test in Solar Tunnel Dryer (April 2017)

B. *Full Load Test of Solar Dryer*

The full load test was carried out in April 2017, the Solar drying of 48 kg of grapes was done, variation of temperature and humidity inside the dryer and outside of dryer was recorded with the help of different device and data was calculated and the graph were draw with the help of recorded data, one day Experimental data is given below:

TABLE III - EXPERIMENTAL DATA ON FULL LOAD

Drying time, hr.	M.C. (% w.b.)	Mw (kg)	ΔT (°C)	Solar intensity (kJ/m2 h)	Heat gain (kJ/ h)	Heat input (kJ/ h)	Eff. (%)
0	85.00	3.054	13.20	1251.04	7736.39	17527.01	44.14
1	83.76	3.22	14.74	1719.18	8161.86	24085.71	33.89
2	82.34	2.96	17.30	2230.24	7510.41	31245.61	24.04
3	80.93	4.31	21.36	2390.94	10953.26	33497.07	32.70
4	78.63	3.08	17.72	2289.53	7816.18	32076.29	24.37
5	76.85	2.30	14.45	1958.94	5829.24	27444.75	21.24
6	75.44	1.4	13.30	1495.40	3546.62	20950.61	16.93

IV. RESULT AND DISCUSSION

After the experimental study, I found that solar dryer (greenhouse type) give more than three to four times heat energy inside the solar dryer than that outside atmospheric temperature. In six hours of continuous drying of grapes under the same zone same time. Solar dryer removes moisture 28.73% from an upper tray and 27.68 % from the lower tray while outside of dryer removed moisture was 9.87%. all the reading is day basis i.e. one day.

V. CONCLUSION

Grapes are considered as one of the most perishable fruits in agricultural produce and have a very short shelf as well as storage life. The storage life of grapes can be increased by drying of grapes in the form of raisins. Similarly, by using proper drying techniques, post-harvest losses of grapes can be reduced.

Traditional technique i.e. direct sun drying is used to drying the agricultural, fruits, vegetables and foods products. This type of drying method is a cost saving, because source of energy is free. Open drying method is weather dependent, and has the problems of contamination, infestation, microbial attacks etc., open drying method is time consuming, and quality is not as desired.

Direct sun drying of Agri-product was a low efficiency method, and product quality was also poor. Solar tunnel dryer is a best way to reduce the post harvesting loss of Agri product like grains, wheat vegetables etc. quality of product achieved by tunnel dryer was good and the efficiency of dryer is high. Solar tunnel dryer is a mild steel structured frame designed covered by UV-stabilized polyethylene sheet. A solar tunnel dryer can be easily installed at any scale.

The performances of green house type solar tunnel dryer after evaluation are as under:

1. The average content of moisture (d.b%of the grapes reduced up to 18.46% (d.b.) in 62 h duration (7 to 8 days) inside solar tunnel dryer as compared to reduction up to 70.80% (d.b.) only in open sun drying.
2. It was observed that the higher moisture removal from grape during 11 am to 4 pm daily was due to a higher amount of solar energy received (324.80 to 635.20 W/m2) during the afternoon period
3. Time of drying with variation in moisture content shows that drying time is fall.
4. Best-fit regression equation variation in content of moisture with drying time was found to be exponential equation [y = a.exp (-b*x)].
5. The average moisture ratio of grapes dried in the solar tunnel dryer was found to be 0.24 as compared to the 0.36 in open sun drying of the grapes.
6. The best ranked thin layer drying model applicable to the variation of moisture ratio with the drying time of grape in solar tunnel dryer was Page equation [y = exp (-a.xb)].
7. The drying efficiency of the solar tunnel dryer varied from 0.61 to 44.14% with the average thermal efficiency of the solar tunnel dryer of 12.23%.

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