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Optimization of Flat Plate Solar Dryer using Taguchi Method

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Abstract: ***Solar form of energy is the most broadly used renewable forms around the globe. The present paper includes the utilization of solar energy in drying food item using a flat plate solar dryer. The experiment is carried with every hour interval and the readings are noted down. The study comprises of timing from morning 9 am to evening 6pm. Around 10 kg of chilli is utilized for the drying purpose. The outcome results were optimized using Taguchi method to identify the optimum configurations for the drying effect. The result shows that, Ambient temperature as 35.5 OC value of air velocity Ambient Relative Humidity as 67.4(%) and Exhaust temperature as 54.2 OC after optimization. Also, the maximum intensity of solar rays are obtained during the daytime at 1 pm.***

Keywords : Solar, flat plate, Taguchi, drying, optimization.

I. INTRODUCTION

Drying and dehydrating is the most significant route which is need to be performed on daily basis where dehydrating take out the moisture available in food items which increase the life of dried products and in comparison to fresh food items. (Majdi and Esfahani, 2018). In drying procedure some variations takes place includes chemical as well as physical and complex too when it go through the estimation depends on numerous points i.e temperature, moisture and time etc. drying process goes through strong track of moisture content needs to be performed under direct radiation of sun. This aspect evaluates the dehydration of food items. (Padmanaban and Palani, 2017).

Some farming products contains very high ratio of moistures and therefore it appears fresh and consumable. Addition and reduction of water with thought of decaying factors is one of the few constituents in the mind of developing countries should loss of such products depends mainly on tropical regions and in subtropical regions. Those losses are mainly of lack of storage facility, rough handling, transportation and many other reasons (Sharma, Garg and Kumar, 2018). Whereas it could be said that, the countries that move towards to be in the race of developing countries able to declining losses related to the agriculture and food areas and improve the qualities of the products to be dried. (Aghaie, Rahimi and Akbarzadeh, 2015)

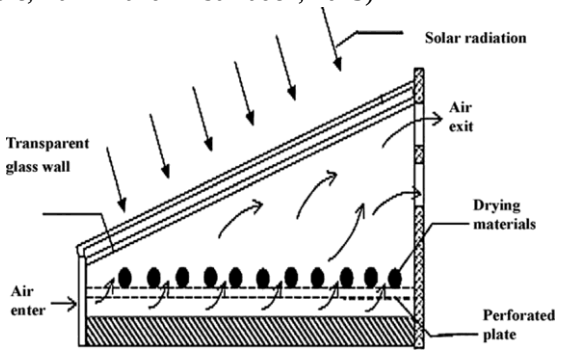

Fig. 1.Solar dryer diagram.

A. Optimization of solar dryers

As the technologies grown solar dryers also enhanced with new design and techniques gives high performance and efficiency working in short span of time. The time period should be important aspect as it makes it highly efficient. (Chen et al. 2011). This leads to attain better results with high performance in solar dryers as compared in traditional techniques which consume very long period of time. This extension regarding the solar based dryer might allow several techniques such as linear regression, in addition with genetic algorithm, including the grey relation analysis and also in Taguchi techniques etc.(Bakari, Minja and Njau,2014).

II. LITERATURE REVIEWS

(Dalvand, Mohtasebi, & Rafiee, 2014) Solar drying usage of products of agriculture which is performed on based upon their moisture contents. Electro Hydro Dynamic linked to PV unit a new technique used for the drying application. In these particular techniques the range of voltage 6-15 KV was introduced in the system framework utilized for the purpose of drying the item in the drying chamber. The entire experiment was enhanced by the means of techniques implemented to develop surface based results which declines the time consumption and is cost effective.

(Verma, Murugesan, & Kumar Kakati, 2019) Research paper presents a study on the efficiency of solar since it can add so much in their scalar powered system field. The research is still race in the field of use of applications based upon solar researchers. Space heating techniques presented in this research by solar coupled by heat pump (SCHP).

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Indian climatic condition used and measured for this purpose. Different constraints of the solar units are improved by the means of developed technique known as Taguchi. Five different constraints used to analyse the best results in this study.

From the study coefficient of performance of the system and efficiency of whole system varies from 38% to 61% and also 1.9%to 3.01% respectively. In Taguchi method, the L27 orthogonal matrix is implemented for the selection of optimum working parameters. From the result outcomes, it was observed that, alteration in the outcomes was observed because of difference in the constraints.

(Liu et al., 2019) In this study which is based on examination and presentation seen in hybrid system consist of PCM with a ventilated tromb wall. The entire parametric constraints regarding the hybrid system were enhanced and developed to obtain the best suited outcomes to work on these configurations. This research work was carried out experimentally depending on the simulations carried out mathematically and numerical basis. The work included a formation of L9 matrix using the Taguchi method. A total number of nine models were made having varying parameter configuration. The analysis was carried out using the graphical representations of ANOVA. The key components considered in the study utilizing the PCM thickness parameter. The optimum value obtained from the complete research was mass flow rate of about 1 kg/s, the dimensions of pipe with 0.6m in dia.,and temperature of 15 degree Celsius with the thickness of the PCM as 20cm.

Table- I: Research done by previous researchers in optimization of solar dryers

Year	Author Name	Method used	Model	Data set	Moisture removing rate (MRR)	Outcome
1.	Foued Chabane (2019)	"A method of drying of apricot from vaporisation."	"A 15mm thicken box made of wood used for sensor with 153cm x 83xm x 10 cm in size respectively"	Apricot	The moisture rate is 0.15 and 0.2 having a total quantity of apricot 370 and 456gm respectively	(Chabane et al., 2019)
2.	(Osodo & Nyaanga, 2018)	"It was analysed with a deviation of MRR used as ANOVA and LSD"	1.2 m x 1.8 m x 0.1 m height respectively calculated as area of the air vent	Grain	0.061 to 0.022 moisture per kilogram an hour	"Grain layer thickness increased from 0.02 to 0.08m respectively for 0.212m/s with flow rate as 0.22 kg of wt. grain/ hour".
3.	(Majdi & Esfahani, 2018)	Projected a theory of removing liquid by Numerical simulation method and this process is further enhanced by Taguchi's method providing a solution with LBM technique implemented to solve hydro dynamically,	L X B X H = 4 cm X 1 cm X 1 cm respectively	apple	Final Drying maximum efficiency recorded as 74.3% with 3.5m/s fan	"As per The Taguchi's design the final ideal conditions found which is in temperature is 60 degree Celsius, Velocity is 0.1m/s and thickness as resulted as final optimized is equal as TR-0.1.It shows the minimal energy depletion "
4.	(Obayopo & Alonge, 2018)	"An implementation of using one way to two way as a study of alteration by ANOVA process get resulted by 95% confidence level ($P < 0.05$)."	It was double walled by double insulated having a fibre glass cylinder to stop energy losses measured as L x W x H= 70 cm x 60 cm x 40 cm respectively.	catfish (Clariasgarie pinus) and tilapia fish (Oreochromi sniloticus	Final Drying maximum efficiency measured as 74.3% with 3.5m/s fan	"It has been proven that the solar glass would be a better unconventional methodology and used as a tool for conserving of different kinds of fishes which are meant providing nourishment and growth.
5.	(Macías-ganc hozo et al., 2018)	"A tabulated result is used in foster TM and star Graphics 5.1TM software to compute linear regression and variance."	Measured as 0.5 m x 0.5m x 1m solar dryer is used	Banana pineapple	Banana 80.22% pineapple 86.36 The various task enhancing process constraint	"Experiments was perform and establish the molecular structure of the banana"

6.	(Padmanaban & Palani, 2017)	"Taguchi Method & Grey Relational Analysis"	In Grey Relation Analysis we found multiple results in the process of optimization constraints was perform for drying with the help of reducing moisture content rate	potato	is 37.36 % and 32.28 %	"The parameters combination had suggests for the high WRR and less Moisture 0 Content have an Initial mass of 500 g, inclination angle of 30 and time period 1-2 AN."
7.	(Salvatierra-Rojas et al., 2017)	"Overall comparisons was evaluate by Duncan's Multiple Range test for milling Head rice yield by conducting it on the (ANOVA)."	The inflatable solar dryer (ISD) was developed within The framework of a cooperation project.	paddy rice	In drying Head rice yield resulted is 57.7%	"The experiment presented shows a 1000kg paddy might be utilized with ease in addition with 14% moisture content in rainy climate conditions.
8.	(Ndukwu & Bennamoun, 2017)	"ANOVA"	Drying chamber measured as 1000 mm x 500mm and a solar collector 500 mm x 500 mm respectively	Red chilli	Sodium Sulphate Dec hydrate 7.6-10%. 26 .7% and 39% compared to drying with Na Cl	"88 - 144 hours need to get drying the Red chili to its moisture level of about 7.6-10%. Drying with Na2SO4.10H2O as thermal energy storage reduced. The drying time by 26 .7% and 39% was compare to drying with NaCl and without any thermal storage."
9.	(N. et al., 2016)	"TVC, TFC, TVN and TMA were analyze using Study of Variance (ANOVA). Post-hoc Tukey's test applied"	It has dimensions of 1m×1m area	Fish	reduction in moisture content from 80% to 15%	"Experimentally dried fish samples by SCD, HAD and FD are of better microbial and biochemical quality as compared to the traditionally open sun dried fish in context to the parameters analyzed."
10.	(Dhumne et al., 2016)	"GA approach employed to optimize the solar tunnel dryer for drying red chilies."	Aluminum sheet with a value of Absorptivity was 0.15. The layer thickness of chilies maintained at 20cm.	red chilies	M R % 45.49	"The optimization of solar tunnel dryer for removing the water from red chilies employed by geometric algorithm and for the particular method geometric algorithm established"
11.	(Monteiro et al., 2016)	"Statistica 7.0 (StatSoft, in addition with ANOVA test"	(Electrolux, Model MEX55, Brazil), at power level of 700 W. the magnetron is ''on'' for 20 s and ''off'' for 9 s, while at 400 W the magnetron is ''on'' for 11 s and ''off'' for 18 s.	Banana	The items were dried by the MWVD as well as MWMFD depicting the declination of 27% & 36%	"the values from the samples of MWMFD were 20-50% greater compared to developed samples of MWVD. "
12.	(Hammond et al., 2018)	"By Solver's function and ANOVA statistics method and a series solution of Fick's second law and calculation performed using Excel's inbuilt"	Measured as 3cm x5 cm torn samples and 2 cm x 2 cm cut samples	algae		"The removal of dehydrating rate and the layer thickness decreases. The Experimental data was model using an analytical series solution of Fick's second Law with the effective diffusivity of 5x10-9 m2/s Approx."

13.	(Zebib et al., 2017)	"2 way analysis of variance (ANOVA) used to calculate"	Measured as 50 cm x 1 cm x 60 cm in area with a wooden frame poles of Capacity 5000 g x 0.1 g	Tilapia fish	Moisture loss (%) 79.54	"In Comparison to tilapia fillet product Open air dryer showed high moisture content rate revealed the most acceptable product obtained from brined product sensory evaluation further raised rack tent dryer which produces better result in drying of water in five day process"
14.	(Vásquez et al., 2016)	"The dryer was advance predictive fuzzy logic control system"	The specifications of solar chamber: 1.2 m x 2.9 m x 0.07 m. there were 40 zinc fins in black, each of 0.03x0.025m	Peach Drying Mushroom Drying Plum Drying Ten	88%	"Mushroom moisture content reduction rate decrease from 85% to 10%. Plum moisture content reduction rate decrease from 79% to 70% and peaches 86% to 55%."
15.	(Khama et al., 2016)	"Anova method is used to implement the result"	indirect solar dryer External dimensions 1.90 ×1.14 × 0.16 m	Tomato	66.56 %	"The moisture content reduction rate of the tomatoes reduced from 14.32 to 0.14 kg water/ kg dry matter after 12 h of drying time."

III. METHODOLGY

The included dryer that was made in this research was made with the help of PVC sheet which is defiant for covering the dryer chamber and collector, angle bar and square bar for making the structure, polythene film, wheels for moving the dryer easily, nuts and bolts for joining the different parts, poly coated wire net, corrupted iron sheet, paint for making the dryer rust proof, solar panel etc. The dryer needs to be bare in the open air. Therefore the dryer must be resistive from the weathering. Other serious topic is to focus the dryer for managing appropriateness. The PVC sheet is very light and resistive to water. According to the parameter of design there needed 4.3 m^2 of PVC sheet of 12 mm. The angle bar was mainly used as the supporting structure of the dryer. The whole dryer structure was supported by the angle bar. There need a 13.5 m of angle bar(3.16 cm) for constructing of collector as well as 41.2 m of angle bar (3.18 cm) for construction of dryer chamber. Mainly the square bars were used in the trays. It was also used in the polythene. They require 51.5 cm of square bar (8 mm) for making the 4 trays and 25.5 cm of square bar (8 mm) for making the roof of the dryer. The polythene is an essential component for trapping solar energy to the dryer. The solar incident of short wavelength enters through the polythene sheet also make the chamber hot. The long wavelength generates into the dryer then intent and makes the chamber hotter. The polythene film also protects from migration of dust or microorganisms into the dryer. There was used 6.2 m^2 of polythene film (1.5 mm thick) both in the dryer and collector.

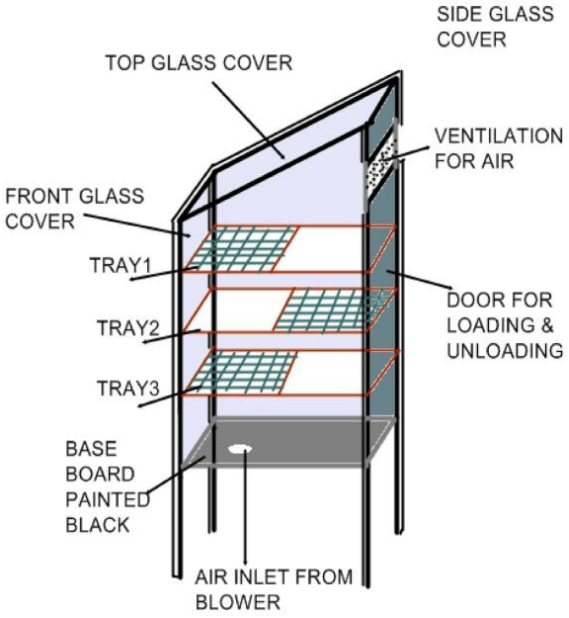

Fig. 2.Flat plate Solar Dryer

Heavy rollers are used to maintain this whole structure so that it can be moved from one place to another. Total number of wheels to be 10 of diameter 100.6 mm which will be used for sustaining this structure. The fixation of dryer component was made by nuts and bolts. This type of fixation endures easiness of handling of all the parts as they can be repaired and replaced when required. The dryer and collector were fixed with nut and bolt so that transportation can be made easily. The required number of piece is 100 with a diameter of 11.7 mm nut and bolt and 20 pieces of 24.4 mm diameter nut and bolt. The wire net is the supporter of the trays which is poly coated. The needed 14.2 m^2 of plastic coated mesh. With the help of coating on the wire net of poly it makes the net stainless and resistive to weathering. The corrugated iron (CI) sheet was kept at the collector. The angle of the collector was 33.25^0 with horizon. The CI sheet is also placed with an angle of 33.25^0.

The main motive of using CI sheet was to increase the surface area of the collector so that more solar radiation can be absorbed to generate more heat. The overall dimensions of CI sheet were 1500mm x 2700mm x1mm. The CI sheet was painted with a black paint. The paint absorbs the solar radiation and heats of the chamber. The yellowish color was used to the MS bar for protecting of metal from corrosion. The yellowish color was used to the MS bar for safeguarding of metal from corrosion. The dimension of solar panel was 609.6mm x 304.8mm x 25.4mm. The CAD and prototype of the solar dryer is shown below in the figure 2

IV. RESULT AND DISCUSSION FOR CHILLI DRYING

The field data during experiment was taken & shown in the following table.

Table- II: Field Investigation Data

SN	Parameter	Symbol	Value
1	Final Mass of Product	M_{wf}	3 kg
2	Pressure Head	h	1.5 m
3	Temperature inside the dryer	T_i	45.5^0C
4	Ambient Temperature	T_{am}	27^0C
5	Collector Temperature	T_c	87^0C

Table- III: Calculated data & Parameter Estimation

SN	Parameter		Equation	Symbol	Value
1.	Moisture to be removed from chilli		2	M_r	7.03 kg
2.	Final moisture of chilli			M_i	12.7%
3.	Pressure throughout the drying bed		5	P	0.346 Pa
4.	Energy Requirement		6	E	16824 KJ
5.	Collector	Area	8	A_c	3.2 m^2
		Length	9	L_c	2.1 m
		Width	Assumed	W_c	1.4 m
6.	Collector useful heat energy gain		10	Q	8553 KJ
7.	Drying rate & average drying rate		11	D_r	0.702 kg
8.	Dryer	Drying Area	16	A_d	2.5 m^2
		Number of Tray	Assumed	N_t	4
		Area of Each tray	17	A_t	0.625 m^2
		Length of tray		L_t	1.5 m
		Width of each tray	18	W_t	0.42 m
9.		Chilli at dryer			
		Chilli at open sun			

Table- IV: Temperature, Relative Humidity, Airflow, & Solar Radiation

Time	Ambient Temp. (^{0}C)	Ambient Relative Humidity (%)	Upper Tray Temp. (^{0}C)	Lower Tray Temp. (^{0}C)	Exhaust Temp. (^{0}C)	Exhaust Relative Humidity	Solar Radiation (W/m^2)
9:00 am	29.3	79.3	40.3	36.2	40.2	62.3	151.4
10:00 am	30.4	77.5	42.7	38	39.4	61.5	160.2
11:00 am	31.5	72.1	49.2	40.4	44.3	51.6	179.4
12:00 pm	33.9	67.2	47.6	46.1	46.5	41.5	211.15
1:00 pm	35.5	63.4	60.1	47.9	54.2	37.2	233.22
2:00 pm	35.3	60.4	57.5	50.6	54.6	32.9	225.19
3:00 pm	34.1	62.4	50.6	51.5	46.9	48.5	195.5
4:00 pm	32.2	54.4	51.9	43.8	48.6	41.1	162.4
5:00 pm	32.3	61.7	45.2	42.9	42.8	49.3	149.3
6:00 pm	32.2	75.2	36.7	37.5	31.8	75.1	108.8
Mean	31.0	68.04	48.37	43.59	44.5	49.8	178.6

Table- V: S/N Ratio

Ambient Temp	Ambient Relative Humidity	Exhaust Temp.	solar Radiation	S/N Ratio
33.9	63.2	46.5	211.15	46.49182
33.9	67.4	54.2	215.35	46.6629
33.9	60.4	54.6	213.41	46.5843
35.5	63.2	54.2	229.62	47.22019
35.5	67.4	54.2	233.22	47.35532
35.5	60.4	46.5	230.14	47.23984
35.3	63.2	54.6	227.32	47.13275
35.3	67.4	46.5	228.84	47.19064
35.3	60.4	54.6	225.19	47.05098

Table- V: Response Table for Signal to Noise Ratios (Larger is better)

Level	Ambient Temp	Ambient Relative Humidity	Exhaust Temp.
1	46.58	46.96	46.97
2	47.12	46.95	47.08
3	47.27	47.07	46.92
Delta	0.69	0.12	0.16
Rank	1	3	2

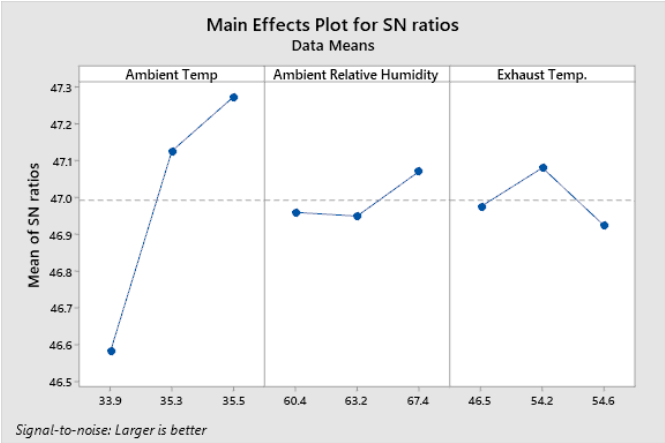

Fig. 3.Plot for S/N Ratio

V. CONCLUSION

In this present study an elaborated survey on solar based system and its development is performed. Solar applications are slowly increasing as it is more profusely available renewable source of energy which has high effectiveness and usefulness in development of a nation which is pollution free. Many researches are till now getting established in this direction to have a newer developments using solar energy. In this study of survey a step towards finding a way of work in the further direction is carried out. The study concludes that in between all the developed methods Taguchi is the most suitable method to develop new parameters for the development in the field of solar based application as it gives suitable values for future betterment of solar devices.

The experiment is effectively carried out and the outcomes were reported every hour. The outcomes depict that radiations of the sun are maximum at 1 pm with a value of 233.22 W/m2. Further, from the Taguchi method, the required S/N ratios developed for the parameters such as flow of air, velocity of air as well as humidity present. The graphs which are formed by the developed techniques shows that the optimized result has value for Ambient temperature as 35.5 OC value of air velocity Ambient Relative Humidity as 67.4(%)and Exhaust temperature as 54.2 OC at the time of 1:00 pm.

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