Optimal Design of Solar Drier for Pulses using OA Design & MRPI Method

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Abstract- **Recently Solar Driers are used to process the pulses in Dhall Industries. The performance of the forced convection Solar Drier for various tilt angles and for various air velocities are analyzed in this paper. The Maximum temperature attainable, Heat Utilization Factor & amount of heat gained are studied as output parameters. The experiment is designed using Orthogonal Array Design. The objective is to make an optimal design of Solar Drier that maximizing all the output parameters using Multi Response Performance Index Method (MRPI method). The optimal tilt angle of solar drier & air velocity that maximizes the output parameters are determined in this study.**

Index Terms- Solar Drier, Orthogonal Array Design, Multi Response Performance Index Method.

I. INTRODUCTION

Sun drying is the most common method of drying used to preserve agricultural products in tropical & subtropical countries. Sun driers are of 2 types. Open drier & Closed drier. Open driers are unprotected from rain, wind borne dust & dirt, infection by insects, birds & animals. Closed drier are preferable than open type as Closed Solar Drier are convenient, protected & hygienic. This paper deals with the optimal design of Closed Solar Drier comprising of collector, suction blower and drying chamber.

II. ORTHOGONAL ARRAY DESIGN

Orthogonal Array (OA's) is mathematical inventions in early 1897 by Jacques Hadamard, a French Mathematician. Later Taguchi has provided the experiment design tool using OA known as 'Interaction Table' to reduce the number of trials.
OA (Orthogonal Array) an experiment design tool minimizes the number of trials needed to perform the experiment. In the performance analysis of solar drier, there are 3 parameters of study & each parameter has 3 levels of variation. Total number of trials needed is 3 x 3 x 3 = 27. Using Taguchi L9 standard array, the number of trials is reduced to 9.

III. EXPERIMENTAL SETUP

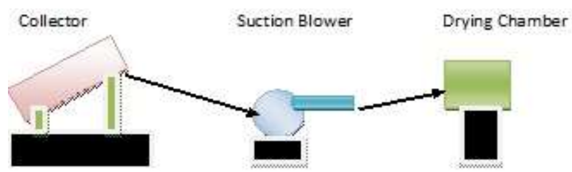

Fig. 1. Sketch explaining Experimental Set up

In order to analysis the performance of solar drier, an experimental setup consisting of solar collector with tilt provision, suction blower with speed variation, drying chamber and drying tray was fabricated.

a. Collector:
The heat absorber of the solar air heater was constructed using 6 mm thick asbestos roofing sheet, painted black & mounted on GI sheet outer box. The space between the asbestos sheet & outer box is filled with foam material of 40 mm thickness with thermal conductivity 0.157x10 -3 W/mK
The solar collector is covered by transparent cover (glazing). The solar radiation that passes through the transparent cover is absorbed by the black asbestos sheet. The glazing has a surface area of 880 mm x 600 mm and transmittance of 0.9 and thermal emissivity of 0.88. One end of the solar collector has a air inlet vent of area 0.001 m2. Atmospheric Air passes through this vent & then gets heated up in the solar collector.

b. Suction Blower:
Suction blower is used to suck the hot air from the collector & send to the drying chamber. A single

phase blower with gate valve is used for the same. The flow velocity can be varied from 0 to 2 m/s.

c. Drying Chamber:
The drying chamber is made using GI sheet. The inlet vent is provided at the lower end & the outlet vent is provided at the top of other end. Access door is provided for the drying chamber.

d. Drying Tray:
The drying trays are contained inside the drying chamber. It is constructed using GI sheet & wire mesh. It is fairly a open structure to allow the drying air to pass through the food item.

IV. METHODOLOGY OF STUDY

The input parameters analyzed are Collector tilt angle, Speed of the air & the time of observation. In order to work out the best stationary orientation of the collector, trials are carried out at 3 levels of tilt angle viz. 10°, 15° & 20°. The air speed is varied from 0.75 m/s to 2 m/s. Speeds above 2 m/s will reduce the maximum temperature attainable. Speeds less than 0.75 m/s will not be economical as the heat gained will be less. The time of observation is fixed as 10 am, 12 noon & 2 pm. The output parameters are Max temperature attainable, Heat gained by air & Heat utilization factor of the drier. The methodology is exhibited using flow chart in fig 2.

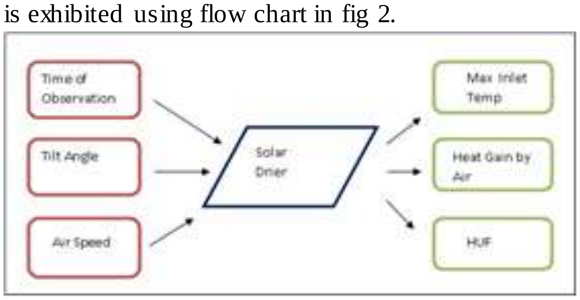

Fig. 2 Flow Chart explaining the Methodology of study

The first hand input data obtained from study is exhibited below as [TABLE 1]

TABLE 1. INPUT VARIABLES

	Factors	Levels		
		1	2	3
A	Time of Observation	10	12	2
B	Tilt Angle of Collector	10	15	20
C	Velocity of Air Flow	0.75	1.25	2

V. CASE ORGANISATION

The study was carried out at Vasumathy Traders, Virudhunagar. They are importers & manufacturers of yellow lintel pulses. The Orthogonal Array Design of Experiments dictates 9 trials. As 3 readings 10 am. 12 noon. & 2 pm. are taken on the same day; all the 9 readings can be completed in 3 days.

The study was carried out for 3 consecutive days at M/s Vasumathy Traders factory, Virudhunagar. All the 3 sunny days were identical in climatic conditions.

The instruments used for study are solarimeter, digital thermometer with 0.1 ° C accuracy and anemometer. The solarimeter is oriented in the same angle as solar collector and the data are collected. The anemometer is placed at the inlet of solar collector to determine the air flow velocity. The data obtained are tabulated in Table 2 Output Data.

TABLE 2. OUTPUT DATA

T No	Factors			Solar Intensity W/m^2	Ambient Air Temp (Ta) ℃	Collector Temp (Tc) ℃	Drier Inlet Temp (Tdi) ℃	Drier Outlet Temp (Tdo) ℃
	A	B	C					
1	10	10	0.75	590	33.5	51.2	48.4	39.1
2	12	10	1.25	598	38.3	54.2	50.4	42.2
3	2	10	2	580	41.3	55.2	51.2	43.6
4	10	15	1.25	580	33.5	48.2	37.4	37.1
5	12	15	2	590	38.3	54.2	59.2	40.2
6	2	15	0.75	568	41.3	61.2	57.1	46.7
7	10	20	2	543	33.5	44.4	34.4	34.2
8	12	20	0.75	602	38.3	60.1	56.2	40.2
9	2	20	1.25	606	41.3	58.4	52.4	44.4

A -Time of Observation
B-Tilt Angle of Collector
C-Velocity of Air flow

VI. CALCULATION OF OUTPUT PARAMETERS

The formulae used for calculations are

Heat Gained by Air = m x Cp x (Tc – Ta)

Where m = ρ A v

Maximum Collector temperature attained is a measurable output parameter.

Heat Utilization = (Tdi – Tdo) / (Tdi – Ta)

TABLE 3. OUTPUT PARAMETERS

Trial No	Factors			Heat Gained by Air	Max Inlet Tem	Heat Utilization
	A	B	C			

				(J/Sec)	p (°C)	
1	10	10	0.75	15.34258	48.4	0.624161
2	12	10	1.25	22.97053	50.4	0.677686
3	2	10	2	32.12985	51.2	0.767677
4	10	15	1.25	21.23691	37.4	0.076923
5	12	15	2	36.75285	59.2	0.909091
6	2	15	0.75	17.24957	57.1	0.658228
7	10	20	2	25.19535	34.4	0.222222
8	12	20	0.75	18.89651	56.2	0.893855
9	2	20	1.25	24.70416	52.4	0.720721

VII. ANALYSIS BY MRPI

The Multi Response problem is converted into a Single Response problem by assigning weights to the responses.

$$W = W1R1 + W2R2 + W3R3$$

This 'W' is termed as Multi Response Performance Index (MRPI). HG is the heat gained by air for various trials. IT is the maximum Inlet Temperature & HU is the Heat Utilization Factor for various trials. The Weightage values are worked using the below relations.

$WHG1 = HG1 / \Sigma HG$.

Similarly

$WIT1 = IT1 / \Sigma IT$.

$WHU1 = HU1 / \Sigma HU$.

TABLE 4 Weightage Values

Trials	HG	W_{HG}	IT	W_{IT}	HU	W_{HU}	MRPI
1	15.34258	0.071534	48.4	0.10835	0.624161	0.11245	0.292335
2	22.97053	0.1071	50.4	0.112827	0.677686	0.122093	0.34202
3	32.12985	0.149805	51.2	0.114618	0.767677	0.138306	0.402729
4	21.23691	0.099017	37.4	0.083725	0.076923	0.013859	0.1966
5	36.75285	0.171359	59.2	0.132527	0.909091	0.163784	0.46767
6	17.24957	0.080426	57.1	0.127826	0.658228	0.118588	0.32684
7	25.19535	0.117473	34.4	0.077009	0.222222	0.040036	0.234518
8	18.89651	0.088105	56.2	0.125812	0.893855	0.161039	0.374955
9	24.70416	0.115183	52.4	0.117305	0.720721	0.129846	0.362334
	214.4783	1	446.7	1	5.550563	1	

TABLE 5. MRPI VALUES

Trial No	Factors			MRPI
	A	B	C	
1	1	1	1	0.292335
2	2	1	2	0.34202
3	3	1	3	0.402729
4	1	2	2	0.1966
5	2	2	3	0.46767
6	3	2	1	0.32684
7	1	3	3	0.234518
8	2	3	1	0.374955
9	3	3	2	0.362334

$$MRPI = WHG\ HG + WIT\ IT + WHU\ HU$$

VIII. RESULTS & DISCUSSIONS

TABLE 6. MRPI VALUES for each level of Input Parameters.

	Factors	Levels		
		1	2	3
A	Time of Observation	0.723453	1.037084	0.994129
B	Tilt Angle of Collector	1.184645	0.99111	0.900954
C	Velocity of Air Flow	1.091902	0.971806	1.104917

The optimal levels for each parameter (Maximum MRPI values) are Bolded in Table 5.

The time of observation has maximum MRPI value at level 2. It agrees with the actual observation, as the temperature inside the drier cabinet is high at 12 noon.

The best tilt angle as suggested by MRPI method is 10°. It tallies with the conclusion specified in reference [1].

The optimal velocity of flow recommended by MRPI method is level 3 (i.e. 2 m/s) as the heat gained increases with the increase in velocity. Further increase in velocity increases the heat loss & hence reduces the Maximum Inlet temperature.

IX. SUGESSTIONS AND SCOPE FOR FURTHER STUDY

The study has been limited to analysis of Heat utilization factor, Heat Gained by Air & Maximum inlet temperature attainable. The study can also be extended to analyze and minimize the heat loss to the surroundings.

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