PAPER

GREY RELATION ANALYSIS OF SOLAR DRYING PROCESS PARAMETER ON COPRA

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ABSTRACT

The methodology for the optimization of the drying parameters on solar drying of copra was investigated and studied in this paper. This paper investigates the influence of the process parameters like initial mass, inclination angle and time period on the output parameters such as weight reduction rate and moisture content. Based on the analysis, optimal levels of parameters were determined and the same was validated through the confirmation test. The confirmation results reveal that, there is considerable improvement in the weight reduction rate, moisture content and grey relational grade and they improved by 37.36%, 32.28% and 32.94 % respectively. It is observed that the drying performance can be effectively improved with respect to the initial parametric setting.

Keywords: Weight Reduction rate (WRR), moisture content, Taguchi, grey relational analysis & design of experiment

1. INTRODUCTION

The use of solar dryers in the drying of agricultural products can significantly reduce or eliminate product wastage, food poisoning and so on, thereby, enhancing productivity of the farmers in obtaining higher revenue. Drying using solar radiation, that is, drying under direct sunlight, is one of the oldest techniques used by man to preserve agriculture based food and non-food products (CHANDRAKUMAR and JIWANLAL, 2013). This form of energy is free, renewable and abundant in any part of the world, especially for countries situated in the tropics. However, in order to maximize its advantage and optimize the efficiency of drying using solar radiation, appropriate measures in terms of technology need to be taken in order to make this technique a sustainable one. Such technology is known as solar drying and it is fast becoming a popular option to replace mechanical thermal dryers, owing to the high cost of fossil fuels which is growing in demand, but dwindling in supply.

SRINIVASAN and BALUSAMY (2015) have studied the performance of forced convection solar dryer, integrated with heat storage materials for processing copra. PARDHI and BHAGORIA (2013) have carried out preliminary investigations and under controlled condition of drying experiments constructed a mixed-mode solar dryer with forced convection, using smooth and rough plate solar collector. DHARMALINGAM *et al*. (2015) have used L_{27} Orthogonal array to determine the Signal-to-noise ratio (S/N ratio) and Analysis of variance (ANOVA) was conducted. Based on the experiments, they concluded that pulse on-time and electrolyte concentration are the most significant parameters for Material Removal Rate (MRR). Gap current and electrolyte concentration which are the influencing parameters for lesser overcut were experimentally investigated. DHARMALINGAM *et al*. (2014a) have found that the influence of the process parameters is through the response surface methodology and grey relational analysis. DHANUSHKODI *et al*. (2014) reported that a directly forced convection solar drier, integrated with recirculation of air has been developed and its performance is tested for drying grapes under the meteorological conditions of Coimbatore, India. The specific moisture extraction rate was estimated to be 0.87 kg/kWh^3. DHARMALINGAM *et al*. (2015) also stated that ANOVA was used for identifying the significant parameters affecting the responses.

2. MATERIALS AND METHODS

2.1 Description of the solar dryer

The developed solar dryer (Fig. 2.1) consists of a glass sheet-covered flat plate solar collector, used to simplify construction and reduce costs. The solar collector is connected directly to the drying chamber without any additional air ducts. The top surface of the insulator in the collector is painted black to absorb solar radiation. The collector is covered with a transparent Ultra Violet (U.V)-stabilized glass sheet that is fixed to the collector frame using reinforced plastic clamps in the drying chamber, and a wire mesh is placed on top of the insulators. A glass is placed on top of the black V groove sheet, on which the product to be dried are spread. This arrangement allows drying air to flow around the whole surface of the product being dried. One side of this sheet is fixed to the drying chamber frame and the other side is fixed to a metal tube, allowing the sheet to be rolled up and down for loading and unloading the dryer. This fixing method is designed to facilitate the replacement of the sheets. In general, the transparent sheet can be used for 1-2 years and the air could last for 3-5 years. The glass is installed at the back of the collector to suck ambient air into the collector. The blowers are intentionally installed below to constantly reduce its temperature, thus, maintaining its efficiency. Both the collector and the drying chamber are installed on mild steel block substructures. All parts of the dryer, including the back insulator and metal frames were designed using a modular concept, which facilitates the transport and installation of the dryer. This solar dryer uses solar energy both in the thermal form of the drying process and in the electrical form for driving the blower, by means of the solar collector and solar module, respectively. Therefore, the dryer could be used in rural areas where there is no supply of electricity. The dryer is a passive system in the sense that it has no moving parts. The sun rays entering through the collector glazing energizes it. The absorption of the rays is enhanced by the inside surface of the collector painted black and the absorbed energy heats the air inside the collector. The greenhouse effect achieved within the collector drives the air current through the drying chamber. If the vents are open, the hot air rises and escapes through the upper vent in the drying chamber, while cooler air at ambient temperature enters through the lower vent in the collector. The Fig. 2.2 shows the copra drying process in the solar dryer.

Figure 2.1. Arrangement of solar dryer.

Figure 2.2. Copra in solar dryer.

2.2. Optimization Methodology

The optimization of process parameters is the key step in the Taguchi method (DHARMALINGAM *et al*. 2014b). Twenty seven experimental runs (L_{27}) based on the Orthogonal Array (OA) of Taguchi methods have been carried out (DHARMALINGAM *et al*. 2014c). The multi-response optimization (Grey Relational Analysis) of the process parameters has been performed for drying, using weight reduction rate and moisture content. The drying time, weight reduction rate and moisture content are noted twice for every trial.

3. RESULTS AND CONCLUSIONS

3.1. Major results and inferences

The assignment of factors with their levels identified inthis investigation are given in Table 3.1.

Table 3.1. Drying process parameters and their corresponding levels.

Symbol	Factors	Level 1	Level 2	Level 3
A	Initial mass Mi (g)	1000	750	500
B	Inclination Angle(°)	30	45	60
C	Time period (Hr)	11AM -12 Noon	1-2 PM	3-4 PM

Based on the Taguchi's L_{27} OA, drying experiments were conducted on solar dryer for copra. The experimental results were gathered for each trial. The S/N ratios were calculated for all the responses since the objective of this work was to maximize the weight reduction rate and the minimization of moisture content. Therefore, for Weight Reduction Rate (WRR), the larger-is-better type was considered and for moisture content, smaller-is-better type was considered for the analysis. The S/N ratio was computed for each of the twenty-seven trial conditions for the weight reduction rate and moisture content and is shown in Table 3.2 below. The weight reduction rate (%) in the Table 3.2 was calculated by measuring the weight of Copra after drying between different time intervals. The optimal setting levels for each factor resulting from the S/N ratios are shown in Table 3.3.

Table 3.2. Experimental results for L_{27} OA of copra.

Trial No.	Initial Mass (Mi) g	Inclination Angle (º)	Time period	Weight reduction rate (%)	Moisture content	S/N Ratio for WRR	S/N ratio for Moisture Content	Grey Relational Weight reduction rate (%)	Grey Relational Moisture content	Grey Grade
1	1000	30	11-12	23.25	69.38	27.328	-36.825	0.5052	0.3358	0.4205
2	1000	30	1-2	36.37	42.18	31.215	-32.502	0.8871	0.4159	0.6515
3	1000	30	3-4	15.12	21.08	23.591	-26.477	0.3940	0.6233	0.5086
4	1000	45	11-12	27.12	33.09	28.666	-30.394	0.5878	0.4707	0.5293
5	1000	45	1-2	34.32	45.60	30.711	-33.179	0.8144	0.4010	0.6077
6	1000	45	3-4	14.46	22.36	23.203	-26.989	0.3831	0.5980	0.4905
7	1000	60	11-12	26.32	35.12	28.406	-30.911	0.6160	0.4560	0.5360
8	1000	60	1-2	33.35	44.06	30.462	-32.881	0.7827	0.4074	0.5951
9	1000	60	3-4	12.21	24.06	21.734	-27.626	0.3468	0.5692	0.4580
10	750	30	11-12	25.32	37.06	28.069	-31.378	0.5479	0.4435	0.4957
11	750	30	1-2	37.35	51.56	31.446	-34.246	0.9249	0.3794	0.6522
12	750	30	3-4	13.35	14.86	22.510	-23.440	0.3333	0.8325	0.5829
13	750	45	11-12	24.35	35.06	27.730	-30.896	0.5704	0.4564	0.5134
14	750	45	1-2	37.31	50.46	31.437	-34.059	0.9233	0.3830	0.6532
15	750	45	3-4	13.35	18.48	22.510	-25.334	0.3650	0.6884	0.5267
16	750	60	11-12	28.52	32.18	29.103	-30.152	0.6716	0.4780	0.5748
17	750	60	1-2	35.51	70.72	31.007	-36.991	0.8556	0.3333	0.5945
18	750	60	3-4	14.14	12.48	23.009	-21.924	0.3457	1.0000	0.6729
19	500	30	11-12	29.35	35.42	29.352	-30.985	0.6414	0.4540	0.5477
20	**500**	**30**	**1-2**	**38.36**	**46.98**	**31.678**	**-33.438**	**0.9663**	**0.3955**	**0.6809**
21	500	30	3-4	15.12	15.90	23.591	-24.028	0.3940	0.7817	0.5879
22	500	45	11-12	28.20	28.08	29.005	-28.968	0.6631	0.5168	0.5900
23	500	45	1-2	38.35	47.42	31.675	-33.519	0.9659	0.3938	0.6798
24	500	45	3-4	16.98	21.90	24.599	-26.809	0.4258	0.6066	0.5162
25	500	60	11-12	26.12	38.48	28.339	-31.705	0.6112	0.4351	0.5232
26	500	60	1-2	39.14	47.00	31.852	-33.442	1.0000	0.3954	0.6977
27	500	60	3-4	13.35	23.20	22.510	-27.310	0.3650	0.5831	0.4741

Footnote: The values showed in bold are optimized values.

Fig. 3.1 shows the residual plots for grey grade. Table 3.4 shows the ANOVA table, which indicates the significance of process parameters on the Weight Reduction Rate and Moisture Content. In the Table 3.4, the F-test is a matter of including the correct variances in the ratio. The F-statistic is this ratio of variation between sample means to the variation within the samples.

Table 3.3. Response table for the grey relational grade.

Process parameters	Level 1	Level 2	Level 3
Initial mass Mi (g)	0.5330	0.5851	**0.5886**
Inclination Angle($0^{c)}$	**0.5698**	0.5674	0.5696
Time period	0.5256	**0.6458**	0.5353
*Optimum Levels	Mean grey grade = 0.5466		

Table 3.4. ANOVA for grey relation grade.

Factors	Design of Factor	Sum of squares	Mean square=sumof squares /2	F value	$F_{0.05}$	%of contribution=sum of squares/total sum of squares
Initial Mass	2	0.002141	0.00107	13.55	0	1.56 significant
Inclination Angle	2	0.015905	0.007952	100.69	0	11.62 significant
Time Period	2	0.117244	0.056822	742.26	0	85.66 significant
Error	20	0.00158	0.000079			1.15
Total	26	0.13687				100%

S = 0.00888699; R-Sq = 98.85%; R-Sq (adj) = 98.50%.
Footnote: The values showed in bold are optimized values.

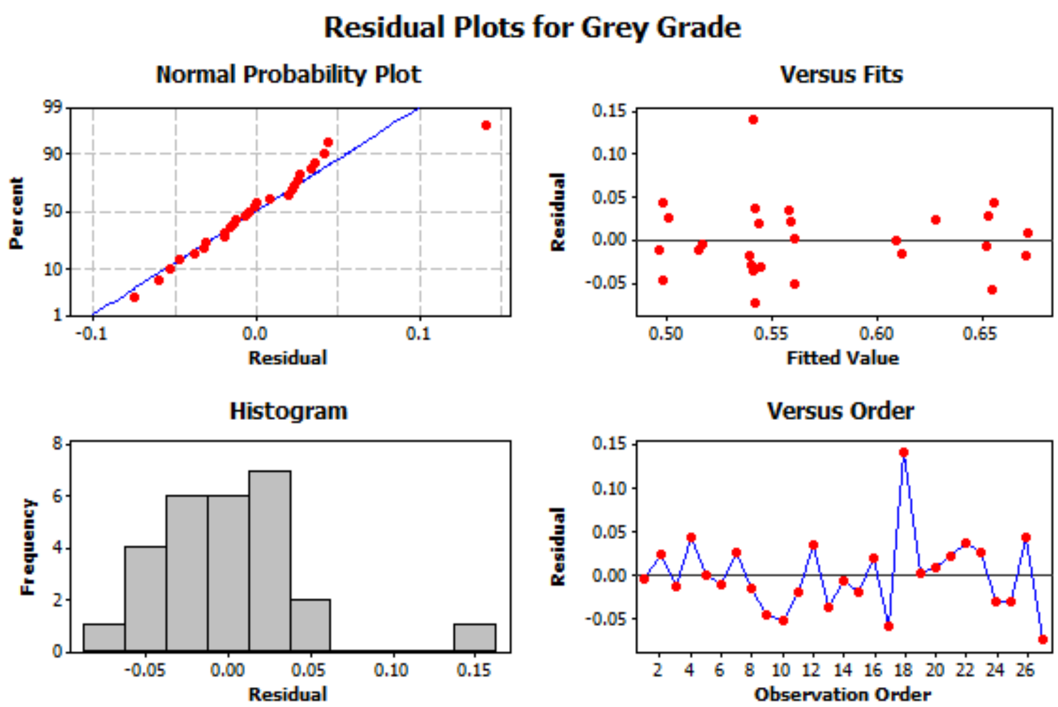

Figure 3.1. Residual plots for grey grade.

3.2. Analysis for weight reduction rate and Moisture Content of copra

The optimal values for the maximum weight reduction rate has an initial mass of 500 g, inclination angle is 30° and time period is between 1-2 AN (after noon). The interaction has been plotted to pictorially depict the interaction process parameters on weight reduction rate and moisture content. In the full interaction plot, two panels per pair of process parameters have been shown in Figs. 3.2 and 3.3.

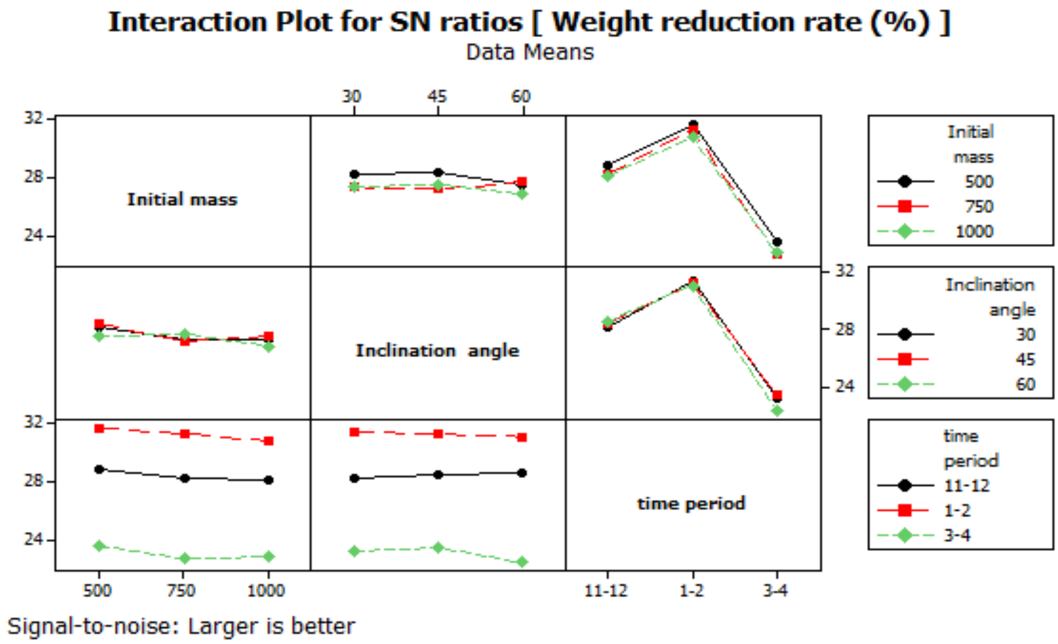

Figure 3.2. Interaction plot for WRR.

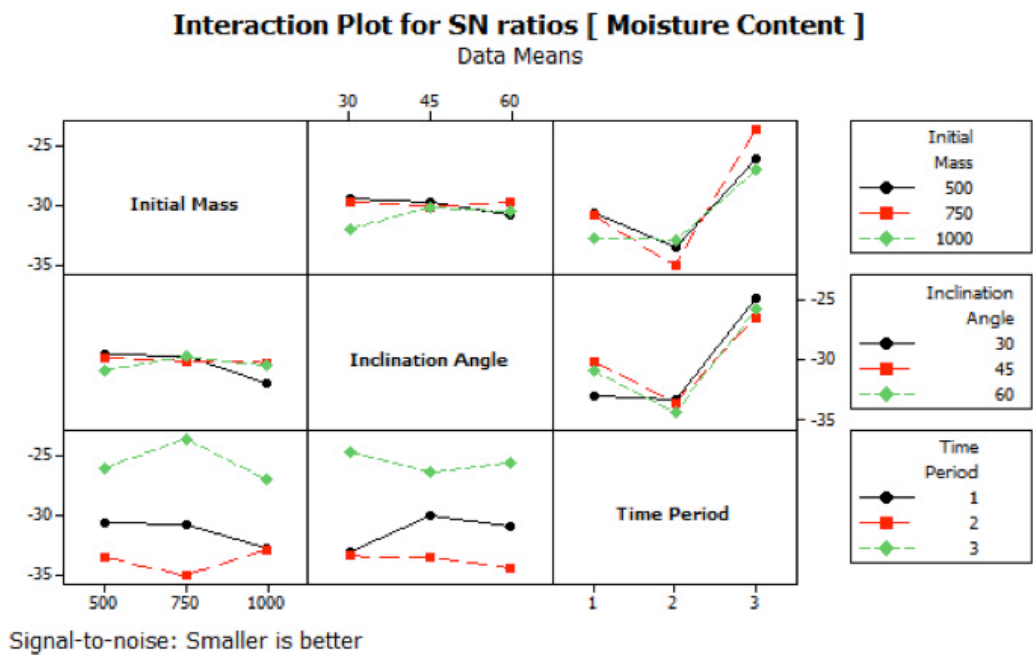

Figure 3.3. Interaction plot for MC.

3.3 Confirmation test

After identifying the most influential parameters, the final phase is to verify the predicted results (WRR and Moisture content) by conducting the confirmation test. The $A_3B_1C_2$ through the GRA is an optimal parameter combination of the drying process. Therefore, the combination $A_3B_1C_2$ was seen as a confirmatory test. The predicted Grey relational grade can be calculated using the optimum parameters as

$$\alpha_{predicted}\, \alpha_m + \sum_{i=1}^{3}(\, \alpha_o - \alpha_m)$$

Where, α_o = average grey relational grade of the optimal level, α_m = overallmean grey relational grade.

α predicted= 0.57045 +(0.58534 - 0.57045)+(0.645329-0.57045)+(0.58534 - 0.57045) = 0.6722

Table 3.4 shows the confirmatory test for weight reduction and moisture content of copra. Based on the confirmatory test, the weight reduction and moisture content were improved by 37.36 % and 32.28 % respectively, with respect to the initial parametric setting. The optimized parameter combination suggested for the higher WRR and Lower Moisture content has an intial mass of 500 g, the inclination angle of 30° and time period of 1-2 hours. The percentage contribution of factors on grey relational grade within a period of time is 86% and inclination angle is 12%. The error and initial mass percentage of contribution of factors are 1% respectively.

Table 3.4. Confirmatory test table.

	Initial levels of drying parameters	Optimal combination levels of drying parameters		
		Prediction	Experiment	Improvement
Level	$A_1B_1C_1$	$A_3B_1C_2$	$A_3B_1C_2$	
WRR (gr)	23.25	38.36	38.36	37.36%
Moisture content	69.38	46.98	46.98	32.28%
Grey grade	0.5123	0.6722	0.6811	32.94%

The following data were observed from the present investigationwhich focuses on optimization and analysis of the solar drying process parameters of copra using Grey Relational Analysis and ANOVA.

a. Based on the confirmatory test, improvement in Weight Reduction Rateand Moisture content is 37.36 % and 32.28 % respectively.
b. The grey relational grade is improved by 32.94 %.
c. The parameter combination suggested for the higher WRR and lesser Moisture Content have an Initial mass of 500 g, inclination angle of 30° and time period 1-2 AN.
d. The results of ANOVA, the time period and Inclinational angle are the significant drying parameters which affect the weight reduction rate and moisture content.

The modified design of the direct air dryer modelled during this research will maximize the efficiency of drying using solar radiation. This modified design can be used to replace mechanicaland thermal dryers which are dependent on high cost fuel. This modified design is brought into existence by keeping the copra as the food component. The researches on carrying out direct drying of other food components using this modified design can be carried out as future research work.

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