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Robust Design Applying Taguchi's Orthogonal Matrices to Determine the Optimal Work Parameters in The Fruit Dehydration Process in A Solar-Gas Hybrid Dehydration Equipment Under Environmental Conditions at 2800 MASL

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Abstracts: In this research work, a prototype dehydrator Solar-gas was designed and manufactured in order to dehydrate tropical fruits under ambient conditions at 2800 MASL. This equipment requires the development of study of parameter variation to determine the most optimal ones under these altitude conditions to which the Taguchi orthogonal matrices have been applied, varying at two levels the different parameters involved such as temperature, relative humidity, mass of product to be processed, product distribution within the equipment. By using this equation, the best combination of them was determined to achieve an efficient process and adequate dehydration. Validation of effectiveness is carried out by determining the homogeneity of the dehydrated product.

Keywords: Dehydrated, Parameters, Taguchi, Noise, Levels, Design, Robust.

1. INTRODUCTION

Dehydration process consists of removing as much of the water contained in a fruit as possible through the flow of heat, the purpose of this is that dehydrated products retain their nutritional properties and remain free of microorganisms that can proliferate and decompose the product under normal environmental conditions or high humidity, with this, the aim is to preserve food for much longer than if it were in its original state, this advantage can be mentioned as the main, but there are others such as requiring less packaging space, preserve nutritional properties, provision of fruits in seasons that are not of production, etc. Regarding disadvantages that could exist, the most common ones that can be mentioned are the partial loss of flavor and texture. In summary, this process is ideal for preserving food for longer and being able to have it available for long periods of time. Some dehydrated products can be seen in Figure 1.

Figure 1. Fruit in normal state with its dehydrated from source "La Privera".

The process itself is done by circulating hot air through the product at temperatures around 50 degrees Celsius, this causes that the water contained in the fruit evaporate and come out through diffusion (see figure 2), This is where the parameters will be varied so that the dehydration process is optimal for the climatic conditions at an altitude of 2800 MASL, achieving drying without crusting or burning (when using LPG) and that the texture is uniform.

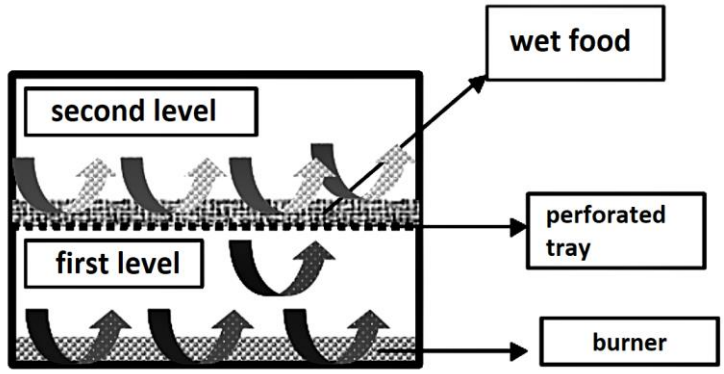

Figure 2. Dehydration process from source "Food drying by direct dryers or hot air convection".

There are several types of dehydrators on the market, existing: solar type, electric, solar plus gas hybrids, among others. All of those mentioned have their own peculiarities. In the case of solar panels, they require the constant presence of solar radiation to be able to work and have the disadvantage of requiring long time for process and dependance on weather conditions. The electric type, as they are operating by electrical resistances, have a high energy consumption which makes the dehydrated product more expensive. As for the hybrid type, there are similar machines to this one in the study presented in this article, but with a different form of operation and in the case of Ecuador, there are no companies that manufacture them. Commercial equipment found with the hybrid system works with LPG only, with convection systems and not of direct conduction, Fiure 3 shows a commercial equipment of this type.

Figure 3. Commercial hybrid solar dehydrator equipment from source "Saecsa Argentina".

In the case of this study, due to cost issues, ease of manufacturing, availability and other factors, the design of a hybrid equipment was appropriated with LPG and air conduction. When dehydrator is working with the conduction LPG, the work parameters must be calibrated so that there is a uniform distribution of heat to each product on trays, and, is necessary to be sure that for those trays that are close to the heat source are not affected by it.

Regarding the way to carry out the work for parameters calibration, the experimental design method that we know as "robust design" will be used using Taguchi matrices in order to obtain the appropriate combination of the main working parameters and obtain the greatest robustness in the equipment. It should be mentioned that robustness as a concept refers to the optimal combination of working parameters in the machine that provides us with the greatest efficiency and effectiveness in the process, thus reducing energy consumption and delivering a product with the desired characteristics.

2. MATERIAL AND METHODS

To carry out the study, a solar-gas hybrid dehydrator was manufactured. The dehydrator works in a mixed regime or independently with each system, that is, only with LPG; or, only with solar radiation (see Fig. 4). To carry out the calibration of the parameters, was necessary to work indistinctly using a mixed modality and only with LPG since for the purpose of the study and calibration of parameters this condition is indifferent.

The equipment has a system similar to that of a conventional oven, in which the burners are turned on to compensate the set temperatures, in case the equipment works at night or in conditions of low solar radiation.

For the working tests, the temperatures, relative humidity, distribution of the product in the chamber and distribution of hot air were varied. The control of temperature and humidity parameters were done through on-off type controllers.

Figure 4. Solar-gas hybrid dehydrator machine on site ready for dehydration.

Taguchi´s array was used in this particular case, 4 parameters were been modified at 2 levels, an L8 arrangement at two levels was used (see figure 5). For the analysis, the presence of noise has not been considered since in this study there is no greater incidence of non-controllable factors.

The gas burner is located at the bottom of the machine and this is the one that comes into operation when the setting temperature varies.

The system controls the temperature and humidity parameters at specific values and if any of them vary, the actuators are activated, a relay coil in the case of the gas system and extractors in the case of humidity.

Arreglo L_8 (fracción 2^{7-4})							
Núm. de corrida	Núm. de columna						
	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

2 factores: columas 1, 2.
3 factores: columnas 1, 2, 4.
4 factores: columnas 1, 2, 4, 7.
5 factores: columnas 1, 2, 4, 7, 6.
6 factores: columnas 1, 2, 4, 7, 6, 5.
7 factores: las siete columnas.

Figure 5. Taguchi´s array

3. RESULTS

The parameters and work levels are shown in Table 1, where level 1 corresponds to the distribution of the product with the first tray to 10 cm from the burner plus a diffuser; and level 2 corresponds to the distribution of the product to 25 cm from the burner with diffuser.

Table 1. Working parameters and levels.

PARÁMETROS DE TRABAJO Y NIVELES			
PARÁMETRO		NIVEL 1	NIVEL 2
1	TEMPERATURE °C	50	45
2	RELATIVE HUMIDITY %	15	10
3	PRODUCT MASS Kg	2	4
4	PRODUCT DISTRIBUTION	1	2

The results of the tests carried out are shown in Table 2. These values were measured based on the percentage of dehydrated product in unsuitable conditions.

Table 2. Working parameters and results.

TEMP.	HUM.	Mass Product	Product Distribution	Pct. NA
50	15	2	1	0,05
50	15	4	2	0,04
50	10	2	2	0,04
50	10	4	1	0,06
45	15	2	2	0,08
45	15	4	1	0,10
45	10	2	1	0,11
45	10	4	2	0,09

The results shown in Table 2 can be seen in Figure 6, a figure in which the most significant factors are shown, those are: temperature, product distribution and humidity.

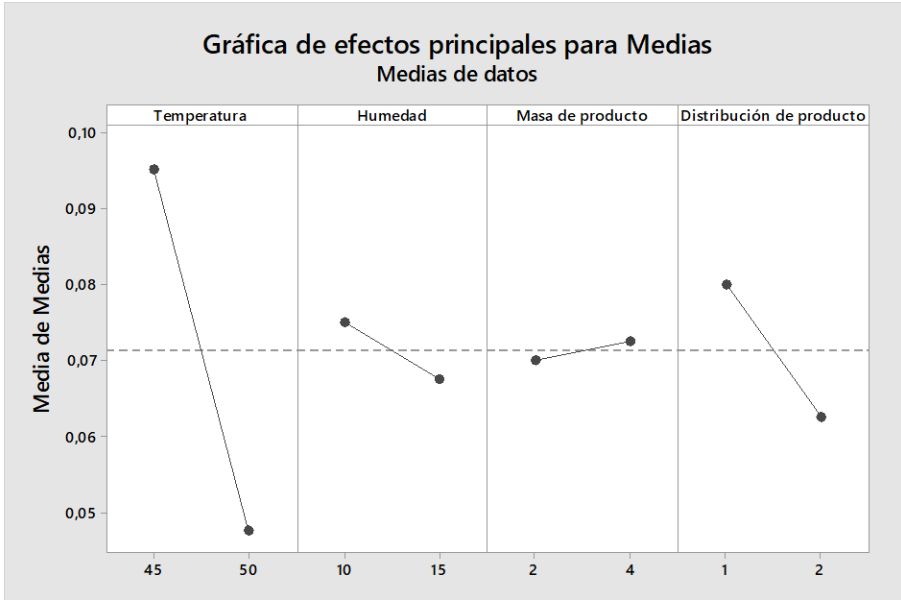

Figure 6. Graphic representation of working parameters and levels

Table 3 shows the calculation of the combinations at the appropriate levels to obtain results that minimize the amount of non-compliant product

Table 3. Calculation of combinations

	T	H	3	MP	5	6	DP
T1	0,19	0,27	0,29	0,28	0,28	0,28	0,32
T2	0,38	0,3	0,28	0,29	0,29	0,29	0,25
SS	0,0045125	0,0001125	1,25E-05	1,25E-05	1,25E-05	1,25E-05	0,0006125
V	0,0045125	0,0001125	1,25E-05	1,25E-05	1,25E-05	1,25E-05	0,0006125
Fexp	361	9	1	1	1	1	49
P1	0,0475	0,0675	0,0725	0,07	0,07	0,07	0,08
P2	0,095	0,075	0,07	0,0725	0,0725	0,0725	0,0625
Y media=	0,07125						

Ef T	-0,02375	Lowest level less average
Ef H	-0,00375	Lowest level less average
Ef DP	-0,00875	Lowest level less average
Yest:	0,035	Y est = Y media + Ef T + Ef H + Ef DP

The product distributed in the equipment and the result for one of the tests can see in Figures 7 and 8.

Figure 7. Product on perforated trays.

Figure 8. Dehydrated product in different combinations of parameters.

4. DISCUSSION

From the obtained results, it can be concluded that, to work with a hybrid solar dehydrator with LPG, the optimal parameters for a good dehydration process at the altitude conditions of 2800 meters above sea level (specifically in the city of Quito) are, process temperature: 50o C, process humidity: 15%, also, the product must be at a distance of at least 25 cm from the burner and with a diffuser element (see Fig. 9).

By placing the parameters at these levels, temperature at level 1, humidity at level 1 and product distribution at level 2, the dehydration process is done at optimal conditions and the dehydrated product is uniform for all the trays at different heights. The mass of product is a low importance parameter in terms of its level, it means that, with a greater or lesser amount of product in each tray of the equipment, the operation is efficient and it was observed that the time is changing for different mass product quantity, it means, more product means more time and less product means less time of process.

Regarding the dehydration of different fruits or products at the same time, it is possible to do it in the same dehydration working process, but in this case the working time change depending on the product and its mass (greater or lesser thickness), therefore, if the work is carried out in this way, one product must be removed before another, a disadvantage of this kind of working process is the change of own smells of each fruit.

Figure 9. Optimal physical conditions for dehydration process.

The mass of the product is not a determining factor in the working process because according to the obtained results, it can be at any quantity of mass at any level of trays.

Because the chamber is controlled in its main working parameters such as temperature and humidity, and there are no unexpected factors that could affect performance, it could be said that there are no noise factors that could interfere with work; in the case of fluctuations in temperature, humidity and environmental pressures, those variation parameters, would not be of importance regarding the work inside of the drying chamber.

There must be a minimum distance from the burner to the first product tray, in this case it was placed at 25 cm away to obtain the best results. As the system is working with LPG by conduction, at distances less than 25 centimeters the results for the dehydration will result not homogeneous, it means that the product will be exposed to higher temperatures and tends to burn its surface.

It was observed that, by placing a heat insulating element between the flame and the first tray, the problem is not solved because the products placed at the borders of trays receive a greater amount of heat and tend to present non-uniform dehydration.

Due to varying environmental conditions, the equipment will always use the LPG option to maintain the optimal temperature, in case of not using this option, and only use the solar dehydration, there is a risk that during periods that there is not solar resource, product will gain humidity again from the environment.

REFERENCES

[1] Humberto Gutiérrez Pulido – Román de la Vara Salazar. "Análisis y Diseño de Experimentos". All rights reserved 2008, McGraw-Hill/Interamericana, S.A. de C.V. ISBN-10: 970-10-6526-3. ISBN-13: 978-970-10-6526-6 (ISBN:970-10-4017-1 previous edition).

[2] Cabascango-Molina O., De la Vega J. 2018. "Manual de deshidratación". Universidad Técnica del Norte (UTN, ECOPAR/PPD). Ibarra – Ecuador.

[3] Karl T. Ulrich – Steven D. Epinger. 2013. "Diseño y Desarrollo de Productos". Fifth edition, McGraw Hill, ISBN 978-607-15-0944-4

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