OPTIMIZACIÓN DE LA RESISTENCIA DE PARTES DE EPS PARA EMPAQUETAMIENTO DE TELEVISORES MEDIANTE EL DISEÑO DE EXPERIMENTOS

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OPTIMIZATION OF THE RESISTANCE OF EPS PARTS FOR PACKAGING TELEVISION THROUGH DESIGN OF EXPERIMENTS

ABSTRACT:

The purpose of this work is to optimize the fracture resistance of the EPS parts used in the packaging of electronic products by using iterative DE-Experiment Design, as a more effective methodology to improve the performance of the productive processes than when It is done in isolation. The iterative DE was applied in a process of molding polyethylene pieces (EPS) in three stages: selection, modeling and optimization. In the selection stage the most important factors of the process were determined; in the modeling stage he determined how the important factors affect the process and in the optimization stage the optimum levels were established. Keeping the process operating within the ranges obtained brought with it a better control of the process with the following benefits: Reduction of the cycle time in 26.6. %; Reduction of the extra monthly time in 77%, and Reduction of charges for returns of rejected products in 85%.

Keywords: Process Improvement Strategy, Design of Iterative Experiments, Optimization of packaging resistance.

RESUMEN:

El propósito de este trabajo es optimizar la resistencia a la fractura de las partes de EPS utilizadas en el empaquetamiento de productos electrónicos mediante el uso de Diseño de Experimentos-DE iterativo, como una metodología más eficaz para mejorar el rendimiento de los procesos productivos que cuando se realiza de forma aislada. El DE iterativo se aplicó en un proceso de moldeo de piezas de polietileno (EPS) en tres etapas: selección, modelado y optimización. En la etapa de selección se determinaron los factores más importantes del proceso; en la etapa de modelado determinó cómo los factores importantes afectan el proceso y en la etapa de optimización se establecieron los niveles óptimos. Mantener el proceso operando dentro de los rangos obtenidos trajo consigo un mejor control del proceso con los siguientes beneficios: Reducción del tiempo de ciclo en 26.6. %; Reducción del tiempo extra mensual en 77%, y Reducción de cargos por devoluciones de productos rechazados en 85%.

Palabras clave: Estrategia de Mejora de Procesos, Diseño de Experimentos Iterativos, Optimización de resistencia de empaquetamiento.

1.- INTRODUCTION

In the industry, the optimization of resources is of the utmost importance due to the globalization of the markets. To meet this challenge, companies can implement strategies that allow them to reach product specifications, prices and on-time deliveries at the lowest possible cost. Also, one of the main concerns in the industry is to make production processes agile and robust. To achieve this, actions can be applied that allow it to focus or "relocate" the processes, reduce their variability, decrease the number of defective parts and have a positive impact on increasing productivity through statistical methods [1, 2] such as they are the Statistical Process Control – SPC and the Design of Experiments - DOE.

A strategy to reduce variation is the search and determination of better operating conditions in a production process. For this, it is recommended that this search be carried out in such a way that, when modifying the current operating conditions, the production process is not disturbed. The design of experiments is a useful method for this purpose [3], in addition, iterative use offers additional advantages to disseminate information from one stage to another, optimizing the use of the materials and methods involved in the experiments and, as a consequence, avoiding isolated and ineffective experiments.

The purpose of this work is to optimize the flexural strength of polyethylene parts of expandable beads-EPS used in the packaging of electronic products, through the iterative use of experiment design as a more effective methodology to improve process performance productive than when carried out without a defined strategy, that is, through the search and establishment of better operating conditions, and are even more effective when integrating non-statistical knowledge about the process in decision making.

The DOE was used in a process of molding parts of EPS. During the EPS molding process, pearl expansion occurs due to small amounts of an expanding agent (pentane) that remains incorporated into the raw material during its manufacture. When applying heat in the form of steam in the pearls, with temperatures above 95 ° C, the polystyrene softens and the pentane contained inside, goes outside, causing foaming in the spheres of the raw material. At this stage there is an increase of up to 50 times the initial volume (www.forel.es/eps_que-es.php). By repeating this process in a closed container, the expanded particles are welded into relatively rigid foam with the desired mold shape (Figure 1).

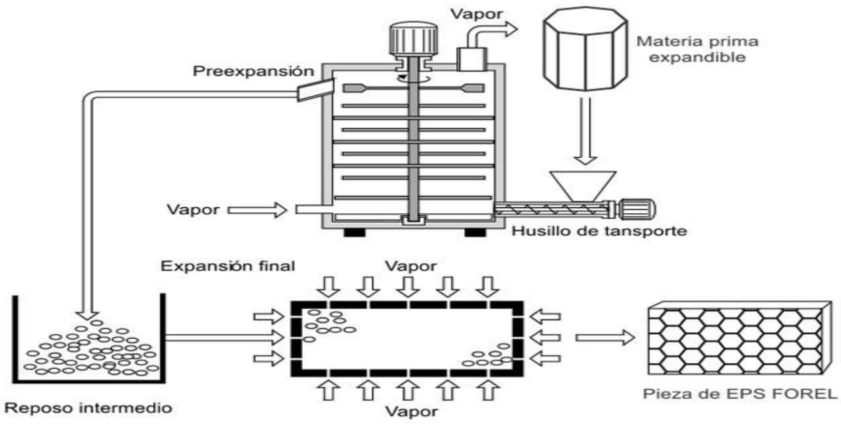

Figure 1. General process of manufacturing EPS parts (www.forel.es/eps_que-es.php)

The size of the expansion of the pearls, the union between them (fusion) and the contour of the mold, are quality characteristics that must be controlled by means of the steam flow, the cooling temperature of the mold and the vapor pressure mainly.

2.- MATERIALS AND METHODS

The materials used (molded parts of EPS), the test procedure, as well as the proposed statistical method (iterative experiment design), used in this work are briefly described below.

2.1.- MATERIALS

The study material is the molded parts of EPS that are used as packaging material for televisions. The packing material for an electronic product unit consists of a set of 4 molded EPS parts: upper right and left, lower right and left (Figure 2). The molded parts have different quality characteristics such as the dimensions, the density of the part and the fusion between the beads, the latter quality characteristic being analyzed in this work. The fusion between pearls must comply with the specifications established by the customer with a nominal value of 47.5 Newton-N and tolerances of ± 12.5 N.

The test procedure of the part is that established by the quality department of the company, which consists of holding the rear end of the part and exerting pressure at a speed of 12.7 cm. x minute at the front end at a distance of 15 cm. of the point of attachment, causing a flexion and until the piece is fractured the value is recorded as "flexural strength" in N, in addition, as indicated in the procedure, the tests were carried out on the upper right parts, considered as the "experimental unit" in this study in order to obtain the observations of each execution or experiment.

Statistical data analysis was carried out with the Minitab® version 16 computer package.

Figure 2. Example of molded EPS parts for television packaging.

The equipment used to measure the resistance of the part is the Newton bending force tester, Chantillón brand, model DFIS 200 S / N 25253, adjustable speed from 0 to 12 inches per minute, with a maximum capacity of 100 N.

2.2.- Method

The statistical optimization method proposed in this work consists of three stages: selection, modeling and optimization. The selection stage is to determine which the most important factors of the process are, the modeling stage is to investigate how important factors affect the process and, finally, the optimization stage is to determine the optimal levels.

2.2.1.- Selection

In general, the number of factors that will be included in the selection stage exceeds three, which makes it almost unlikely to carry out Complete Factorial Experiments, therefore, it is recommended to develop Factorial Fractional Experiments –DFF, with DFF being understood as the designs in which a part or fraction of the treatments of a complete factorial are properly chosen, with the intention of studying the effect of the factors using less experimental runs [4], since the objective is to maintain the least number of experimental executions so as not to interrupt the process during the execution of the experiment and thus keep the costs as low as possible.
It is not recommended to use full factorials at this stage because they increase costs since the number of experimental executions increases exponentially, for example; having five factors with two levels each, this results in 32 treatments, when increasing one more factor, the treatments increase to 64, basically the formula for the total number of treatments is 2^k, where; k represents the number of factors with two levels, in the case of factors with three levels is 3^k.

At this stage, it is recommended to carry out experiments that include the factors that the experimenter considers that may influence in some way the response variable, which is usually the result of a brainstorming session in which people involved in the process (operators, personnel of the departments of maintenance, quality, engineer etc.).

2.2.2.- Modeling

In this stage, the factors that were most important in the selection stage are used. The factors that are identified as important are investigated in greater detail in subsequent experiments [5, 6]. It is recommended to use fractional factorial experiments of type 3 if the number of important factors exceeds three or use full factorials if the number of important factors is less than or equal to 3. In some situations, especially when there are three important factors, it is recommended to use complete two-level factorial experiments to reduce the number of treatments. It is also advisable to use the response surface methodology [1, 3]. The factorial space considered in this stage must be of smaller volume than that considered in the previous stage and contain the optimum operating conditions recommended in the previous stage.

The Complete Factorial Designs, understood by CFD to the methodology that allows to study the individual effect and the interaction of two or more factors (X) on one or more response variables (Y) [4, 8], are the most efficient when Experiments are carried out to study the effects produced by two or more factors, they have the advantage of being more efficient than one-factor experiments, they are necessary when an interaction or more interactions occur. Currently, they can be investigated, allow estimating the effects of a factor at various levels of other factors and is equivalent to several single factor experiments when there are no interactions [3, 7].

2.2.3.- Optimization

At this stage the most important factors are already known and how they affect the response variable and other operating conditions better than those obtained in the selection stage, and that, if it does not have a general optimum, it is close, therefore, it is It is necessary to use a statistical method that does not disturb the process too much and make an optimization around the new optimum. It is recommended to use the Response Surface Methodology (when it is suspected that it is not near the global optimum) or the Evolutionary Operation (EVOP) if it is suspected that it is near the global optimum.

The factorial space considered at this stage must be of smaller volume even than that of the modeling stage; however, it is difficult to define criteria, so that non-statistical knowledge of the process or experience is of paramount importance. The Evolutionary Operation method is based on small changes of the factors under study, with a 2^k design with a central point and changes to a new operating condition are only made when there is statistical evidence [2, 3].

3.- RESULTS

The proposed method was used in a molding process of polyethylene parts, which uses expandable beads (EPS). The size of the expansion of the pearls, the union between them (fusion) and the contour of the mold are characteristic of quality, which must be controlled by means of the steam flow, the cooling temperature of the mold and the vapor pressure mainly. To "mold" the pieces, the molds are filled with the correct amount of pearls by means of air guns, then the steam is supplied to the molding chamber and is brought into contact with the pearl through the spiers to heat the pearl, which causes an expansion that forces the pearls to form the mold figure by merging with each other. Subsequently, the mold is cooled by water and / or vacuum.

In phase 1. - Selection of important factors, it was decided to carry out a Fractional Factorial Design 2^{7-3}, with eight experiments, because it was considered to analyze 7 factors, which, at the discretion of the personnel involved in the process, were the most important for the merger of the part and considering the time and waste limitation generated. Table 1 shows the levels of each factor, which were determined by assigning the current operating ranges (level 1 = maximum range, level 2 = minimum range), based on the experience of the personnel involved, it was also assumed that the Higher order interactions are negligible.

Table 1. Factors and their levels of the stage I experiment

LETTER	FACTOR	LEVEL (-)	LEVEL (+)
A	General Steam Pressure	60 psi	40 psi
B	Steam Time Fixed Side	15seconds	10 seconds
C	Pressure Mobile Side	1.3 bar	0.5 bar
D	Steam Time Mobile Side	15 seconds	8 seconds
E	Fixed Side Pressure	1.3 bar	0.5 bar
F	Air pressure	110 psi	100 psi
G	Cooling Time	6.0 seconds	0.5 seconds

The objective of the experiment is to verify if there is an effect due to different factors in the response variable and to determine which of the two levels produce better results in said response variable. Table 2 presents the data (six replies) of the flexural strength of the parts during the design 2_{III}^{7-4} experiments. For a deeper treatment of the topic Fractional Factorial Designs see Montgomery [3].

Table 2. Fracture resistance (in N) data of design parts 2_{III}^{7-4} (stage I)

	F A C T O R							**REPLICA**					
Experiment	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**1**	**2**	**3**	**4**	**5**	**6**
1	-	-	-	+	+	+	-	34	45	39	40	40	42
2	+	-	-	-	-	+	+	55	59	53	54	60	53
3	-	+	-	-	+	-	+	45	34	41	30	42	51
4	+	+	-	+	-	-	-	46	44	39	48	40	49
*5	-	-	+	+	-	-	+	0	0	0	0	0	0
6	+	-	+	-	+	-	-	47	56	45	44	39	54
7	-	+	+	-	-	+	-	43	47	48	60	39	40
*8	+	+	+	+	+	+	+	0	0	0	0	0	0

*** Note: Experiment 5 and 6 the test values were Zero, this means that the flexion value was zero when the piece fractured.**

To confirm the significance of the factors under study, the Analysis of Variance was carried out [4, 8]. The analysis of variance (Table 3) can be performed using contrasts or based on the procedure described in Montgomery [3].

Table 3. Variance analysis table for fracture resistance data of design 2_{III}^{7-4}

Source	Degrees of freedom	Sum of Squares	Average of Squares	F-Value	p-value
A	**1**	**325.5**	**325.5**	**13.23**	**0.001***
B	1	111.0	111.0	4.51	0.040
C	**1**	**5655.0**	**5655.0**	**229.76**	**0.000***
D	**1**	**8347.7**	**8347.7**	**339.16**	**0.000***
E	**1**	**247.5**	**247.5**	**10.06**	**0.003***
F	1	67.7	67.7	2.75	0.165
G	1	5022.5	5022.5	204.06	0.000*
Error	40	984.5	24.61		
Total	47	20761.5	47		

The factors that are considered important are all those that are significant, in this case a level of significance of 1% is being used. One factor is significant if F is greater than $F_{0.01,1,40} = 7.31$ important factors are: General Steam Pressure (A), Mobile Side Pressure (C), Mobile Side Steam (D), Fixed Side Pressure (E) and Cooling Time (G).

When there is an effect due to the factors, the next step is to determine which of the two levels is the one that produces the best effect on the performance of the response variable, so the average responses that are presented in Table 4 were calculated, indicating with an asterisk the optimum levels for each factor, concluding that the best level of factor operation are: for the General Vapor Pressure (A) is 40 psi, Mobile Side Pressure (C) is 1.3 bar , Mobile Side Steam (D) is 15 seconds, Fixed Side Pressure (E) is 32.0 psi and Cooling Time (G) is 6.0 seconds.

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Table 4. Average responses of the factors under study

FACTOR	General Vapor Pressure: A	Side Pressure Mobile: C	Steam Moving Side: D	Fixed Side Pressure: E	Cooling Time: G
Level 1 (-)	31.6	45.1*	47.4*	36.5*	44.5*
Level 2 (+)	36.9*	23.4	21.1	32.0	24.0

In the second stage (Process Modeling) the work team decided to use a Complete Factorial Design 2^3 to analyze only the three most important factors of the 5 selected in the results of the previous stage, this due to the time limit available from The machine under study. The levels of these factors were determined close to those that were optimal in the selection stage or the same. The reason for the reduction of the factorial space is to explore other points close to the recommended operating conditions.

Table 5. Factors and levels under study in stage II

LETRA	FACTOR	Low level (-)	High Level (+)
G	Water Cooling	2.5 seconds	6.0 seconds
C	Pressure Mobile Side	0.9 bar	1.3 bar
D	Steam Mobile Side	12 seconds	15 seconds

The levels for the three parameters to be analyzed were established as follows: Level 2 (+) = "best impact" level (according to stage I) and Level 1 (-) = Midpoint of the levels of stage I, the other factors were "fixed" at their best level (stage). The factors and their levels are summarized in Table 5.

The objective of this stage is to further analyze the effect of the three main factors and their interactions [3, 4], and determine how the factors affect the response variable, and determine the level that best results in the variable of response to determine better operating conditions. Table 6 shows the fracture resistance of the parts manufactured during the Design 2^3 experiments.

Table 6. Fracture resistance data of design parts 2^3 (stage II)

Experiment	1	2	3	4	5	6
1	50	42	48	52	50	51
2	50	51	48	44	51	46
3	48	44	45	44	48	48
4	49	54	52	48	52	52
5	48	52	51	45	49	48
6	54	47	55	48	52	44
7	48	48	49	51	50	45
8	58	48	48	52	56	53

Table 7 summarizes the analysis of variance for the fracture resistance data of design 2^3. It can be seen that the steam time of the moving side is significant at 1% and the interaction between it and the Pressure on the mobile side is significant at 5%, so you should analyze and look for the best combination between these two factors.

Table 7. Analysis of variance for the fracture resistance data of the design 2^3

Source	GL	S.C.	M.C.	F-Value	P-Value
G	1	21.333	21.33	2.24	0.143
C	1	4.0833	4.083	0.43	0.517
D	**1**	**70.083**	**70.083**	**7.34**	**0.010****
G*C	1	3.000	3.000	0.31	0.578
G*D	1	0.333	0.333	0.03	0.853
C*D	**1**	**52.083**	**52.083**	**5.46**	**0.025***
G*C*D	1	5.333	5.333	0.56	0.459
Error	40	381.667	9.541		
Total	47	537.917			

In order to analyze the interaction and establish the "Optimal" levels of the three factors, it was necessary to consider the interaction of the factors. Table 8 shows the average responses of the DC interaction and shows that the low level of factor D; 12 seconds together with the high level of factor C; 1.3 bar, produces the value of the response variable closest to the specification nominal (47.5 N.).

Table 8. Average response of the CD interaction

FACTOR / NIVEL		
Steam Mobile Side D	**Pressure Mobile Side C**	**AVERAGES**
12 seconds	0.9 bar	48.83
12 seconds	1.3 bar	47.33
15 seconds	0.9 bar	49.16
15 seconds	1.3 bar	51.83

In the last phase (Optimization) it was decided to use the method of operational evolution - EVOP [2,3], where the factors 'Mobile Side Steam' and 'Mobile Side Pressure' were analyzed in order to find the conditions that gave the value closer to the target value in response variable to obtain operating conditions The work team decided to start as point 1 with the 15-second conditions of 'Moving side steam' and 1.3 bar of 'Moving side pressure', with variations of + 3 seconds and + 0.4 bar, respectively. A factorial experiment 2^2 was carried out, with the current conditions as the central point. A reading was taken at each of the 5 points of the design in a random order thus completing cycle 1, obtaining the following readings, Point 1: 49 N., Point 2: 47 N., Point 3: 54 N., Point 4: 54 N and Point 5: 56 N (Figure 3). From cycle 2 they are carried out in an EVOP worksheet.

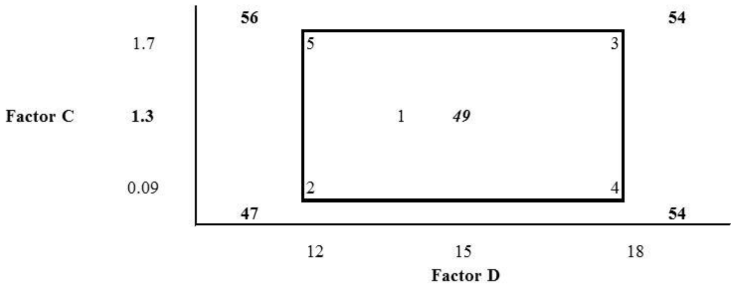
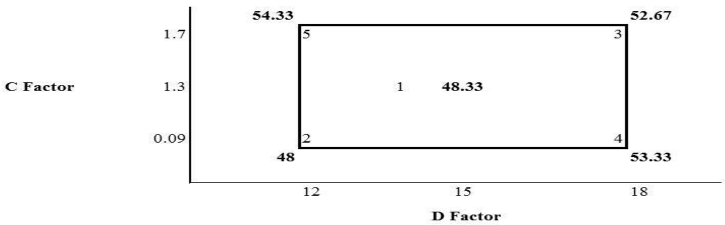


Figure 3. Factorial design 2^2 for EVOP cycle number one.

In the second cycle, five observations were taken again and the following readings were obtained, Point 1: 48 N., Point 2: 49 N., Point 3: 50 N., Point 4: 52 N and Point 5: 51 N. When applying the decision criteria, it was concluded that the effects of the two factors and the interaction are less than their error limit, therefore, they are considered non-significant. Then, a third cycle was started taking five observations with the following values of the response variable at each point: Point 1: 48 N., Point 2: 48 N., Point 3: 54 N., Point 4: 54 N and Point 5: 56 N. When applying the decision criteria again, it is observed that the effect of the factors is significant and the difference between point 1 and point 3 and 4 or 2 and 5 is greater than their error limit (Table 9).

Table 9. Results of EVOP cycle number three



Effects with 95 % Error Limits	Error Limits for Averages : + - **1.819**	
Factor D : Steam Mobile Side	1.833	(+ -) 1.819
Factor C: Pressure Mobil Side	2.833	(+ -) 1.819
Interaction DxC	-3.500	(+ -) 1.819
Change in mean	3.000	(+ -) 1.619

With this operating condition, the results show that the factors Steam time moving side and Pressure moving side are significant, then the average level closest to the objective 47.5 N., is setting the factors to the vapor pressure of the moving side at 0.9 bar with 12 seconds of Steam time moving side, therefore, it could be concluded that better operating conditions have been found with point 2. Table 10 shows the operating conditions established after the application of the Experiment Design methods, indicating with an asterisk (*) the critical factors.

Table 10. Operating ranges established for the molding machine.

PARÁMETER	RANK	
	Minimum	Maximum
General Steam Pressure	40 psi	60 psi
Steam Fixed Side	10 seconds	15 seconds
Pressure Mobile Side *	0.9 bar	1.3 bar
Steam Mobile Side *	12 seconds	15 seconds
Pressure Fixed side	0.5 bar.	1.3 bar
Air Pressure	100 psi	110 psi
Cooling Time *	2.5 seconds	6.0 seconds

To verify that the process operates better, a confirmation run was carried out with the proposed operating parameters (table 10). When comparing the parameters of the distribution of the response variable before and after this work, it is observed that the improvement in the process was mainly due to the reduction of the variation of the process (Table 11).

Table 11. Estimators of the parameters of the distribution of the response variable

	AVERAGE	DEVIATION
Before	45.05 N	3.99
After	47.70 N	2.65

4.- CONCLUSIONS AND RECOMMENDATIONS

The use of the proposed method fulfilled the purpose of optimizing the production process of EPS parts by applying the design of experiments in a structured and iterative way, through the search and establishment of better operating conditions, than when the experiments are carried out. It is carried out in isolation and along with that the statistical methods add objectivity to the decision-making process, allowing the decisions made to have a great impact on increasing the productivity of the company.

4.1.- CONCLUSIONS

The application of the DOE is a powerful tool to improve production processes, product quality and increase the productivity of companies, as shown in this article, where the performance of a manufacturing process was improved resulting in parts that meet with the specification "Breaking strength" and with less variation, which resulted in keeping the process operating under statistical control, reflecting the following benefits:

1. Increasing the actual capacity of the process (Cpk) from 0.84 to 1.59, therefore, a reduction in the percentage of waste of raw material by 68%;
2. Reduction of machine operating cycle time from 75 seconds to 55, increasing machine availability by 36%; impacting a reduction in extra monthly time by 77%;
3. Charges for defective product returns were reduced by 85%.

Note: Data on % waste reduction, monthly extra time reduction, and % reduction on return charges were provided by the company's bail bonds department.

In addition, when the Experiment Design methods are used to improve the performance of the processes, it was concluded that the benefits obtained also depend, in large part, on the knowledge that the people involved had about the process under study, since, at their criteria and their experience, the factors that could affect the response variable and the levels (low and high) of these factors were selected. Although the non-statistical knowledge of the process is important, the statistical part is very important, so it should not be forgotten that there must be an important interaction between everyday knowledge and scientific (statistical) knowledge, since both are research inputs scientific.

4.2.- RECOMMENDATIONS

For the selection of the Experiment Design method to be applied, it is advisable to use the following criteria:

- If what is desired is to analyze the effect of 5 or more factors (up to a reasonable number, for example, 15), and it can be reasonably assumed that some higher order interactions are insignificant, 2^{k-p} fractional factorial designs are easy of applying and used to select the important factors.
- If what you want is to analyze the effects of 3 or 4 factors, as well as their interactions, the complete 2^k Factorial Designs are the most efficient because they are the only ones in which all possible combinations of factor treatments in each are analyzed, Full test or replica of the experiment.
- If what is desired is to analyze two factors without interfering with the production process, the Evolutionary Operation method is appropriate because the experiment is based on small changes of the factors under study.

It is convenient to involve "experts" in the process under study, in order to obtain a theoretical-practical balance in decision-making on the scope of the results obtained from the statistical analysis and reach reasonable conclusions, and then establish ways of action.

In addition to the use of DOE to find the operating conditions (temperature, time, etc.) in which the defects are reduced or a better process performance is achieved, its application is highly recommended to compare two or more materials in order to choose the best, to compare several measuring instruments to verify if they work with the same precision and accuracy, reduce the cycle time of the process, and support the design or redesign of new products or processes [4], to mention only a few cases.

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