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RESEARCH METHODOLOGY FOLLOWED FOR OPTIMIZATION OF PRODUCTION SYSTEM FOR ROLL BOND EVAPORATOR OF DOMESTIC REFRIGERATOR

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Abstract: - This research paper deals with the research methodology followed for optimization of production system for Roll Bond Evaporator of Domestic Refrigerator. Methodology refers to more than a simple set of methods; rather it refers to the rationale and the philosophical assumptions that underlie a particular study. The study adopts an analytical research design with experimental approach. Beginning with the research questions that emerged after the review of literature on the productivity and the optimization of various industrial processes, the paper focuses on to the different set of methods used to operationalize the research work. Among other facets shared by the various fields of inquiry is the conviction that the process be objective to reduce a biased interpretation of the results. Another basic expectation is to document, archive and share all data and methodology so they are available for careful scrutiny by other scientists, thereby allowing other researchers the opportunity to verify results by attempting to reproduce them. In the present study, a quantitative method was used, which was clearly identified in view of the specific objectives of the study.

Keywords: Research Methodology, Optimization, Quantitative Method.

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INTRODUCTION

There are many ways of outlining the basic method shared by all fields of scientific inquiry. In the present investigation, the researcher followed a general research method as follows

1. Define the question
2. Gather information and resources (observe)
3. Form hypothesis
4. Data Collection
5. Analyze data
6. Interpret data and draw conclusions

In the present study, a careful collection of facts was undertaken by the researcher to ensure the validity of the facts. Wherever, possible, the data for the same variable was recorded from more than one source. This allowed the careful scrutiny of the recorded data, which would give more appropriate results. The present study was carried out in three steps involving reconnaissance, sampling/data generation and analysis, followed by interpretation of the results.

Roll Bond Evaporators

Aluminum Roll-Bond evaporators provide unique designs flexibility for direct cooling refrigeration systems. Roll-Bond evaporators deliver efficient thermal performance in a product that can be shaped to fit most applications. They are often supplied in four different manufacturing stages: inflated, stamped, welded, painted (with connectors - aluminum, copper aluminum or heat exchanger). The integration of the primary and secondary plates, together with the aluminum thermal conductivity, supply excellent thermal transfer characteristics and can be offered in different finishes.

Manufacturing process of Roll Bond Evaporators

The manufacturing process of the production of roll-bond evaporator panels (evaporators) is divided into phases:

- casting of the broadband;

- rolling of broadband into the band for evaporators;
- roll-bonding at the warm formation temperature on the Expandalstation;
- recrystallization annealing in the chamber furnace;
- inflation of imprinted channels on the evaporation panel on hydraulic recasting machines;
- final dimension cut with mechanical scissors to customer request and packaging;
- stamping with stamping tools on eccentric presses and packaging.

Data Collection

All the data collection procedures have been described in this section of the paper. Each day of data collection involved the following activities:

When?	**What?**	**Who?**
Before going out to collect data	• Checked that data collection personnel has all the materials necessary for field visits and confirmed transport arrangement on each day • Called each facility to be visited and confirm appointment	Research scholar
On arrival at the plant	• Introduced survey team and reminded staff of the visit's purpose • Verified and completed the outlet information on first page of the data sheet • Collected and recorded necessary data from relevant sources • Checked all data entered into the data collection form before leaving	Research scholar

	facility	
After Data Collection	• The researcher checked all the data sheets after the data collection process and ensured that all the data required for this study has been collected	Research scholar

Care was taken to ensure the accuracy and reliability of data collection procedure. This involved the activities described below.

Field Supervision

With respect to the objectives of the study, care was taken to constantly monitor the field (actual working area of the Roll Bond Evaporator manufacturing unit) to ensure that all the necessary data points have been recorded. Furthermore, it was ensured that the technicians follow the standard procedures while doing their work in Roll Bond Evaporator manufacturing unit.

Daily Check of completed Data Collection Sheets

It is important that the researcher review completed Data Collection forms at the end of each day to check that the data are complete, consistent and legible. This procedure was carried throughout the data collection period as once the team has left the field; it becomes difficult to verify information that may be missing or incomplete. After this the forms were then safely stored until completion of data collection.

Validation of Data Collection

The cross checking of data recorded for different procedures carried out in the Roll Bond Evaporator Manufacturing plant as well with different technician was carried out by collecting random samples of the time needed for various operations. The data thus obtained was compared with the data recorded earlier to check the differences. This validation was performed regularly to ensure validity of the data. Any discrepancies between the results were cross checked and correct data was followed by ensuring the conformance to the appropriate data collection protocol.

Storing the Generated Data

Completed forms were copied and stored in waterproof plastic bags in the field, in a location that was protected from moisture, direct sunlight, rodents and insects. Originals were stored in a separate location from copies. All original data collection forms, including those for validation visits, were transferred to the safe location upon completion of fieldwork. This data was then entered in the database prepared using MS-Office package.

Field Data Collection

The field data was collected for the following steps, sample data sheet is as follows

SN	Process	Time Needed (Secs/Mins)	No. of Workers Engaged in the Activity
1	Printing – Bonding		
2	Bonding - Pressing and Rolling		
3	Pressing and Rolling - Rerolling Elongation		
4	Rerolling Elongation – Annealing		
5	Annealing – Month Opening		
6	Month Opening – Inflation		
7	Inflation – Size Height Cutting		
8	Size Height Cutting – Brazing		
9	Brazing – Leak Testing		
10	Leak Testing – Powder Coating		
11	Powder Coating – Packing and Dispatch		

Frequency of data generation

In this study, the data generation was carried out for the period of six weeks. Subsequent to which, the data was analysed and on the basis of results obtained after this analysis, necessary changes were made in the plant lay-out and again the data was collected for a period of five weeks.

Design of Experiments and ANOVA

Design of experiments (DOE) is a powerful advanced statistical technique used to study the effect of several process variables affecting the response or output of a process. It was developed in the early 1920s by Sir Ronald Fisher, at the Rothamsted Agricultural Field Research Station in London, UK. Fisher's approach to experimentation was a direct replacement of traditional one-factor-at-a time approach to experimentation. Over the past several years, DOE has gained worldwide acceptance as an essential ingredient for improving process effectiveness and product quality. This recognition is partially due to the work of Taguchi, a Japanese engineer and an international quality management consultant, who promoted the importance of making robust products and processes through the application of DOE. Many manufacturers have reported a number of successful applications of DOE for improving product performance, improving product life and reliability over the years.

Guidelines for Designing Experiments:

To use the statistical approach in designing and analyzing an experiment, it is necessary for everyone involved in the experiment to have a clear idea in advance of exactly what is to be studied, how the data are to be collected, and at least a qualitative understanding of how these data are to be analyzed.

Recognition and statement of the problem:

It is necessary to develop all ideas about the objectives of the experiment. In this work careful collection of all the processes was carried out and a list of specific processes was prepared. Since, all these processes contribute substantially to better understanding of the phenomenon being studied and the final solution of the problem, this process was given due importance.

Choice of factors, levels and range

One of the first things in conduction of a DOE evaluation, is to select the factors that will be examined. This can be accomplished by using following selection criteria. The criteria of interest include:

- Scope refers to the applicability of the factor which is relevant in many different situations. Pieces of equipment etc., or is it restricted to relatively few situations?
- Economy of control- can control of the factor be effective with relatively low cost?
- Practicality of control-disregarding cost would control of the factor actually happen, or would it be too cumbersome to put into effect?
- Significance as a Single Factor Acting Alone-what is the estimated influence of the factor on its own?

- Significance of the Factor as a part of any Multiple-Factor interactions-How influential might the factor be in combination with other factors?
- Originality of work-Does inclusion of this factor advance knowledge or simply repeat work already performed?
- Specific Company Needs- Is inclusion of the factor essential to make the results meaningful to specific company.

Once the experimenter has selected the design factors, he/she must choose the ranges over which these factors will be varied, and the specific levels at which runs will be made. Thought must also be given to how these factors are to be controlled at the desired values and how they are to be measured. In this study, the data pertaining to time and productivity (response variables) was collected after making changes in the plant lay out. Choice of Design involves the consideration of sample size, the selection of suitable run order for the experimental trials, and the determination of whether or not blocking or other randomization restrictions are involved. In selecting the experimental design, it is important to keep the experimental objective in mind.

Taguchi Method

The technique of laying out the conditions of experiments involving multiple factors was first proposed by the Englishman, Sir R. A. Fisher. The method is popularly known as the factorial design of experiments. A full factorial design will identify all possible combinations for a given set of factors. Since most industrial experiments usually involve a significant number of factors, a full factorial design results in a large number of experiments. To reduce the number of experiments to a practical level, only a small set from all the possibilities is selected. The method of selecting a limited number of experiments which produces the most information is known as a partial fraction experiment. Although this method is well known, there are no general guidelines for its application or the analysis of the results obtained by performing the experiments. In view of this Taguchi constructed a special set of general design guidelines for factorial experiments that cover many applications.

Robust Design method is central to improving engineering productivity. Robust Design method, also called the Taguchi Method, pioneered by Dr. Genichi Taguchi, greatly improves engineering productivity. By consciously considering the noise factors (environmental variation during the product's usage, manufacturing variation, and component deterioration) and the cost of failure in the field the Robust Design method helps ensure customer satisfaction. Robust Design focuses on improving the fundamental function of the product or process, thus facilitating flexible designs and concurrent engineering. Indeed, it is the most powerful method available to reduce product cost, improve quality, and simultaneously reduce development interval.

Minimum number of experiments to be conducted

The design of experiments using the orthogonal array is, in most cases, efficient when compared to many other statistical designs. The minimum number of experiments that are required to conduct the Taguchi method can be calculated based on the degrees of freedom approach.

$$N_{Taguchi} = 1 + \sum_{i=1}^{NV} (L_i - 1)$$

For example, in case of 8 independent variables study having 1 independent variable with 2 levels and remaining 7 independent variables with 3 levels (L_{18} orthogonal array), the minimum number of experiments required based on the above equation is 16. Because of the balancing property of the orthogonal arrays, the total number of experiments shall be multiple of 2 and 3. Hence the number of experiments for the above case is 18.

Assumptions of the Taguchi method

The additive assumption implies that the individual or main effects of the independent variables on performance parameter are separable. Under this assumption, the effect of each factor can be linear, quadratic or of higher order, but the model assumes that there exists no cross product effects (interactions) among the individual factors. That means the effect of independent variable 1 on performance parameter does not depend on the different level settings of any other independent variables and vice versa. If at any time, this assumption is violated, then the additivity of the main effects does not hold, and the variables interact.

Designing an experiment

The design of an experiment involves the following steps

- Selection of independent variables
- Selection of number of level settings for each independent variable
- Selection of orthogonal array
- Assigning the independent variables to each column

- Conducting the experiments
- Analyzing the data

The details of the above steps are given below.

Selection of the independent variables

Before conducting the experiment, the knowledge of the product/process under investigation is of prime importance for identifying the factors likely to influence the outcome. In order to compile a comprehensive list of factors, the input to the experiment was obtained from all the people involved in the roll bond evaporator manufacturing process.

Deciding the number of levels and Selection of an orthogonal array

Once the independent variables were decided, the number of levels for each variable was decided. The selection of number of levels depends on how the performance parameter is affected due to different level settings. If the performance parameter is a linear function of the independent variable, then the number of level setting shall be 2. However, if the independent variable is not linearly related, then one could go for 3, 4 or higher levels depending on whether the relationship is quadratic, cubic or higher order.

Before selecting the orthogonal array, the minimum number of experiments to be conducted was fixed based on the total number of degrees of freedom [3] present in the study. The minimum number of experiments that must be run to study the factors was more than the total degrees of freedom available. In counting the total degrees of freedom the investigator commits 1 degree of freedom to the overall mean of the response under study. The number of degrees of freedom associated with each factor under study equals one less than the number of levels available for that factor. Hence the total degrees of freedom without interaction effect is 1 + as already given by above equation. The minimum number of experiments was decided to be 6 per week.

Assigning the independent variables to columns

The order in which the independent variables are assigned to the vertical column is very essential. Finally, before conducting the experiment, the actual level values of each design variable were decided.

Conducting the experiment

Once the orthogonal array was selected, the experiments were conducted to know the manpower requirement for different processes, which were part of the roll bond manufacturing process. Care was taken that all the experiments were conducted. The performance parameter under study (manpower requirement) was noted down for each experiment to conduct the sensitivity analysis.

Analysis of the data

Since each experiment is the combination of different factor levels, it is essential to segregate the individual effect of independent variables. This can be done by summing up the performance parameter values for the corresponding level settings. For example, in order to find out the main effect of level 1 setting of the independent variable 2, sum the performance parameter values of the experiments 1, 4 and 7. Similarly for level 2, sum the experimental results of 2, 5 and 7 and so on. Once the mean value of each level of a particular independent variable is calculated, the sum of square of deviation of each of the mean value from the grand mean value is calculated. This sum of square deviation of a particular variable indicates whether the performance parameter is sensitive to the change in level setting. If the sum of square deviation is close to zero or insignificant, one may conclude that the design variables is not influencing the performance of the process. In other words, by conducting the sensitivity analysis, and performing analysis of variance (ANOVA), one can decide which independent factor dominates over other and the percentage contribution of that particular independent variable.

A main cause of poor yield in manufacturing processes is the manufacturing variation. These manufacturing variations include variation in manpower skills or efficacy of the equipments, variation in raw materials, and drift of process parameters. These sources of noise/variation are the variables that are impossible or expensive to control.

The objective of the robust design was to find the controllable process parameter settings for which noise or variation has a minimal effect on the product's or process's functional characteristics. It is to be noted that the aim is not to find the parameter settings for the uncontrollable noise variables, but the controllable design variables. To attain this objective, the control parameters, also known as inner array variables, are systematically varied as stipulated by the inner orthogonal array. For each experiment, a series of new experiments are conducted by varying the level settings of the uncontrollable noise variables. The level combinations of noise variables are done using the outer orthogonal array.

The influence of noise on the performance characteristics can be found using the ratio where S is the standard deviation of the performance parameters for each inner array experiment and N is the total number of experiment in the outer orthogonal array. This ratio indicates the functional variation due to noise. Using this result, it is possible to predict which control parameter settings will make the process insensitive to noise. Hence, based on the results of the experiments, it was observed that when the roll bond evaporator manufacturing plant's layout is modified, the time needed to manufacture the units i.e. roll bond evaporators was reduced significantly. This was evident from the overall batch production of the roll bond evaporators, which showed significant ($P<0.05$) improvement. Besides, the manpower required to complete the process also showed remarkable decline. This decline was evident throughout the roll bond evaporator manufacturing process as well as sub-processes.

Statistical Analysis of data:

Statistical methods were used to analyze the data so that results and conclusions are objective rather than judgmental in nature. Often we find that simple graphical methods play an important role in data analysis and interpretation. Because many of the questions that the experimenter wants to answer can be cast into a hypothesis testing framework, hypothesis testing and confidence interval estimation procedures are very useful in analyzing data from a designed experiment. It is also usually very helpful to present the results of many experiments in terms of an empirical model, that is, an Equation derived from the data that expresses the relationship between the response and the important design factors.

Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) is an incredibly effective method for analyzing the data obtained from properly and scientifically designed experiments. Analysis of Variance is a statistical method used to intercept experimental data and make necessary decisions. Analysis of Variance is a statistically based decision tool for detecting any difference in average performance- of groups of items tested. The decision rather than using pure judgment, takes variations in account. The essence of ANOVA is that the total amount of variation in a set of data is broken down in two types, that the amount which can be attributed to chance and that amount which can be attributed to specify cause.

The ANOVA technique is important in the context of all those situations where we want to compare two or more than two populations. In such circumstances one generally does not want to consider all possible combinations of two populations at a time for that would be able to arrive at a decision. This would consume lot of time and money and even then relationships remains unidentified (particularly the interaction effects). Therefore, one quite often utilizes the ANOVA technique and thoroughly investigates the differences among the means of all the populations simultaneously.

Methodology of ANOVA:

In any experiment where several factors are allowed to vary, a situation called experimental error exists. Experimental error is the random error created in the experiment from chance variation in uncontrollable factors such as quality material, environmental conditions, and operators involved. Taken together experimental error creates a background "noise" in the data.

ANOVA measures this background noise. Then ANOVA measures the amount of signal creates a real change in the response variable. If a factor is creating a signal that has more magnitude than the background noise, we say that this factor has the significant effect. Factors that cannot overcome the noise are called insignificant.

Thus through ANOVA technique one can, in general investigate any number of factors, which are hypothesized or said to influence the dependent variable. One may investigate the difference amongst various categories within each of these factors, which may have a large number of possible values. We are said to use one-way ANOVA and in case we investigate two factors at the same time, then we use two-way ANOVA. In two or more way ANOVA the interaction (i.e. interaction between two independent variable factors) if any, between two independent variables affecting a dependent variable can as well be studied for better decision.

Using PASW 18.0 Software for performing ANOVA

In the present study, Analysis of Variance procedure was carried out by using the PASW 18.0 software. The analysis was separately carried out for different sub-processes. Further to ANOVA, a Post Hoc Test procedure was also carried out to know which means differ. In addition to this the Tuckey's HSD test was also carried out.

Statistical Analysis of Data and Significance Level

Analysis of data was done with the help of suitable statistical tests. The descriptive statistics, such as mean, standard deviation, mode, frequency, percentage, minimum and maximum, etc. were determined from the collected data. The comparative assessment was done using ANOVA as well as suitable graphs. All the data generated during the study was processed using various statistical tests with the aid of Statistical Package for Social Sciences (SPSS) 18.0 software. The significance level was chosen to be 0.05 (or equivalently, 5%) by keeping in view the consequences of such an error. That is, researcher wants to make the significance level as small as possible in order to protect the null hypothesis and to prevent, as far as possible, from inadvertently arriving at false conclusions

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