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# Application of Taguchi Method for Optimization of Process Parameters in Improving the Productivity of Corrugation Operation

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**ABSTRACT:**
*Taguchi Method is a powerful statistical approach to enhance the Quality & Productivity of Process by optimization of Process Parameters (Nutek Report on Basic Design of Experiment). The Objective of this study is to implement the Design of Experiments (DOE) based Taguchi Method in Corrugation operation for optimizing the Productivity. The Orthogonal Array, Signal to Noise Ratio, individual factor influence is employed to study the Quality Characteristics on Corrugation Operation. In Research Process, critical control factors namely Raw Material, Preheating Temp., Flute Profile, Speed of Corrugating Roll, Adhesive, & Pressure Roll Temp were considered. Accordingly, a suitable orthogonal array was designed & experiments were conducted. After conducting the experiments, signal to noise ratio was calculated for determining optimum parameter value. These results were compared with the results of full factorial method.*

**Keywords:** Corrugation Process; Design of Experiment; Orthogonal array; S/N Ratio; Taguchi Method

## I. INTRODUCTION

Taguchi Method is a standardized method of Design of Experiment (DOE) developed by Dr. Genichi Taguchi to study the effects of multiple variables simultaneously for determining the optimum result (A Primer of Taguchi Method by Ranjit Roy).Taguchi parameter design technique improves product/process design via consistency of performance & robustness (insensitivity toward uncontrollable factor) (Roy, Ranjit K. Design of Experiments, 2001). The main applications of Taguchi Methodology are Optimize Designs using analytical simulation studies, Select better alternative in Development and Testing, Optimize manufacturing Process Designs,& solve manufacturing problems (Taguchi Experiment Design, Kraus International Publications, 1987). Success in achieving the desired results involves a careful selection of process parameters & bifurcating them into control and noise factors. Selection of control factors must be made such that it nullifies the effect of noise factors. Taguchi Method consist experiment design by standardized orthogonal array to analyze the factor influence and predict the Quality Characteristics (W. T. Foster, Basic Design of Experiment, 2000).

Here, an attempt has been made to demonstrate the application of Taguchi Method to improve the productivity of Corrugation operation by optimization of process parameters. Productivity is the important component to evaluate the performance of an enterprise, growth of the MSMEs, Economic growth of the nation, & employment generation (Vrat,P., Sardana, G.D. and Sahay, B.S. 1998). So it is highly desirable to improve Quality & productivity of process.

## II. APPROACH TO PRODUCT/PROCESS DEVELOPMENT

Many methods have been implemented & developed over the years to optimize the production process. Some of the most used approaches are given below:

**1.1 Build-Test-Fix**

The "Build-test-fix is the most primitive approach aimed at achieving performance on target and reduced variation by process/product tested approach and reworked each time till the target value is not achieved. It is based on trial methodology according to the resources available, instead of trying to optimize it.

**1.2 One Factor at a Time**

The "One-factor-at-a-time" is a tedious, time consuming, & expansive approach aimed at optimizing the process by running an experiment at one particular condition and repeating the experiment by changing any one control factor till the effect of all control factors analyzed. The main disadvantage of this optimization technique is not consider the interaction between control variables and only individual factor influence are taken into account.

**1.3 Design of Experiment**

The Design of Experiment is a statistical technique in product/process development that provides a predictive knowledge of a complex, multi variable process. It is considered as best tool for optimum factor solution under multiple variable condition with minimum effort. Following are the major approaches to DOE:

**1.3.1 Full Factorial Design**

A Full factorial experiment is an experimental design technique that takes all possible combination of each factor for studying the effect of each factor, & the effects of interactions between factors on the response variable. If there are k factors with 2 levels then full factorial design has $2^k$ runs.

**1.3.2 Taguchi Method**

The full factorial design becomes laborious & complex method since it requires a large number of experiments to be carried out by considering all possible control variable combination. To overcome this problem, Taguchi introduced an experiment design technique by using orthogonal array to study the entire parameter range with lesser number of experiments. Taguchi recommends the use of loss function to measure the performance characteristics that are deviating from the target value. The value of Loss function is further transformed to signal-to-noise ratio. Usually, there are three categories of performance characteristics (nominal the best, smaller-the-better, and larger-the-better) are used to analyze the S/N ratio.

## III. Steps involved in Taguchi Method

Taguchi Method is used to improve the Quality of products & process (System of Experiment design, UNIPUB, 1987). Following are the application steps are:

**1.Brainstorming**: This is necessary first step in any application. The session should include firsthand knowledge of the project.

- Determine what you are after and how to evaluate it. When there is more than one criterion of evaluation, decide how each criterion is to be weighted and combined for the overall evaluation.
- Identify all influencing factors and those to be included in the study.
- Determine the factor levels.
- Determine the noise factor and the condition of repetitions.

**2. Designing Experiments:** Experiments was designed by using factors & levels determined in the brainstorming session. To design the experiments, implement the following:

- Select the appropriate orthogonal array.
- Assign factor and interaction to columns.
- Describe each trial condition.
- Decide order and repetition trials.

**3. Running Experiments:**

- Run experiments in random order when possible.

**4. Analyzing Results:** Analysis is performed to determine the following

- The Optimum Design
- Influence of Individual Factors

## IV. APPROACH TO THE EXPERIMENT DESIGN

According to steps that are involved in Taguchi Method, a series of experiments are to be conducted. Here a case study, optimization of corrugation process by using Taguchi Method is given. The procedure is given below:

### 4.1 Identification of Main Function, Objective & Result, and Quality Characteristics

- **Main Function:** Corrugation operation on Kraft material using Corrugated Machine
- **Objective & Result** –Determine best process parameter settings.
- **Quality Characteristics** – Measure Rate of Production (Output/time).

### 4.2 Determine System Parameters (Control Factors, Noise Factors, Corrugation Machine Parameter)

- **Control Factors:**

1. Type of Raw Material (Corrugating Medium & Liner material).
2. Preheating Temperature
3. Profile of Corrugating Roll
4. Speed of Corrugating Roll
5. Type of Adhesive used
6. Pressure Roll Temperature

- **Noise Factors**

1. Humidity
2. Vibrations
3. Temperature
4. Operator Skill
5. Machine Condition

- **Corrugation Machine Parameters**

1. Paper Roll Diameter – 1.5 m
2. Width of Paper Roll – 3.3 m
3. Steam Pressure – 15 bar
4. Spray Damper Pressure – 2 bar
5. Corrugating Roll Material – Chrome Molybdenum Steel
6. Roller Coating Thickness – 0.05 to 0.08 Tungsten Coating Thicknesses
7. Hardness of Roller - > 55-60 HRC
8. Pressure Roll Diameter – 250 mm
9. Flute Roll Diameter – 320 mm

### 4.3 Identify the Objective Function

Objective function: Larger the Better

S/N Ratio for this function: $\eta = -10 \log_{10}(_i^2)/n)$

Where n=Sample Size, Y=Rate of Production

### 4.4 Define the Control Factor Level

**TABLE: 4.1 CONTROL FACTORS & THEIR LEVEL**

| FACTORS | LEVEL 1 | LEVEL 2 |
|---|---|---|
| Raw Material (Corrugated Medium & Liner) | Kraft Medium & Kraft Liner | Kraft Liner & Semi Kraft Fluting |
| Preheating Temp. | 192.2 C | 180 C |
| Flute Type of Corrugated Roll | Coarse Flute Type | Fine Flute Type |
| Speed of Corrugated Roll | 30 m/min | 40 m/min |
| Adhesive Type | High Amylose Hybrid | Conventional Corn Starch Type |
| Pressure Roll Temp. | 115 C | 130C |

(Source: Author Observation)

**4.5 Experimental Design by Orthogonal Array:**

Orthogonal array define the number of factors and their appropriate level. The total number of factors available divided by the number of repetitions yield the size of the array for design.

A number of factors are identified for an optimization of corrugation process.

- Time available is two weeks during which only 25 tests can be run
- Three repetitions for each trial condition is desired
- Array size 25/3 = L-8 Array
- Six from the identified 2- Level factors can be studied.

**TABLE: 4.2 EXPERIMENT DESIGN BY ORTHOGONAL ARRAY**

| Experiment No. | Control Factors | | | | | |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | F |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 2 | 2 | 2 |
| 3 | 1 | 2 | 1 | 2 | 1 | 2 |
| 4 | 1 | 1 | 2 | 2 | 1 | 1 |
| 5 | 2 | 2 | 2 | 1 | 1 | 1 |
| 6 | 2 | 2 | 1 | 1 | 2 | 2 |
| 7 | 2 | 1 | 2 | 1 | 2 | 1 |
| 8 | 2 | 2 | 2 | 2 | 2 | 2 |

(Source: Author Observation)

**4.6 Conducting the Matrix Experiment**

In accordance with the above OA, experiments were conducted with their factors & their level as shown in table 4.2. Each of the above 8 experiments were conducted 3 times (24 experiments) to account for the variations that may occur due to the noise factors. The Table 4.3 shows the measured value of rate of production obtained from different experiments.

**TABLE 4.3: MEASURED VALUE OF RATE OF PRODUCTION**

| EXPERIMENT NO. | RATE OF PRODUCTION (OUTPUT/TIME) (m/min) | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | MEAN |
| 1 | 250 | 255 | 248 | 251 |
| 2 | 268 | 270 | 271 | 269.6 |
| 3 | 260 | 258 | 260 | 259.33 |
| 4 | 300 | 295 | 298 | 297.66 |
| 5 | 265 | 264 | 265 | 264.66 |
| 6 | 208 | 210 | 210 | 209.33 |
| 7 | 245 | 244 | 246 | 245 |
| 8 | 290 | 288 | 290 | 289.33 |

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### 4.7 Examination of Data

The following are the experimental results of the work carried out.

### 4.7.1 Experimental Details

Since, the Objective Function (Rate of Production) is Larger-the-Better type of control function, was used in calculating S/N Ratio.The S/N ratios of all the experiments were calculated and tabulated as shown in Table 4.4.

**TABLE: 4.5 TABULATED S/N RATIO**

| Experiment No. | S/N Ratio (db) |
|---|---|
| 1. | 47.99 |
| 2. | 48.62 |
| 3. | 48.27 |
| 4. | 49.47 |
| 5. | 48.45 |
| 6. | 46.42 |
| 7. | 47.78 |
| 8. | 49.23 |

(Source: Author Observation)

The S/N ratio for the individual control factors are calculated as given below:

$A_{a1}= (\eta_1+\eta_2+\eta_3+\eta_4)$, $A_{a2} = (\eta_5+\eta_6+\eta_6+\eta_7+\eta_8)$, $B_{b1} = (\eta_1+\eta_2+\eta_4+\eta_7)$, $B_{b2} = (\eta_3+ \eta_5+ \eta_6+ \eta_8)$

$C_{c1} = (\eta_1+ \eta_2+ \eta_3+ \eta_6)$, $C_{c2} = (\eta_4+ \eta_5+ \eta_7+ \eta_8)$, $D_{d1} = (\eta_1+ \eta_5+ \eta_6+ \eta_7)$, $D_{d2} = (\eta_2+ \eta_3+ \eta_4+ \eta_8)$

$E_{e1} = (\eta_1+ \eta_3+ \eta_4+ \eta_5)$, $E_{e2} = (\eta_2+ \eta_6+ \eta_7+ \eta_8)$, $F_{f1} = (\eta_1+ \eta_4+ \eta_5+ \eta_7)$, $F_{f2} = (\eta_2+ \eta_3+ \eta_6+ \eta_8)$

$\eta_k$ is the S/N ratio corresponding to Experiment k.

Average S/N ratio corresponding to Raw Material at Level 1 = $A_{a1}/4$

Average S/N ratio corresponding to Raw Material at Level 2 = $A_{a2}/4$

Similarly S/N ratio is calculated corresponding to Preheat Temp., Flute Type, Speed, Adhesive, and PressureRoll Temperature.

**TABLE: 4.6AVERAGE S/N RATIO FOR EACH FACTOR**

| Level | Raw Material | | Preheat Temp. | | Flute Type | | Speed | | Adhesive | | Pressure roll temp | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sum ($A_{aj}$) | Avg S/N ratio | Sum ($B_{bj}$) | Avg S/N ratio | Sum $C_{CJ}$ | Avg S/N ratio | Sum $D_{DJ}$ | Avg S/N ratio | Sum $E_{EJ}$ | Avg S/N ratio | Sum $F_{FJ}$ | Avg S/N ratio |
| **1** | 194.35 | 48.58 | 193.9 | 48.47 | 191.5 | 47.88 | 190.6 | 47.65 | 194.2 | 48.55 | 193.7 | 48.43 |
| **2** | 191.88 | 47.97 | 192.4 | 48.1 | 194.93 | 48.73 | 195.6 | 48.9 | 192.1 | 48.02 | 192.5 | 48.13 |

(Source: Author Observation)

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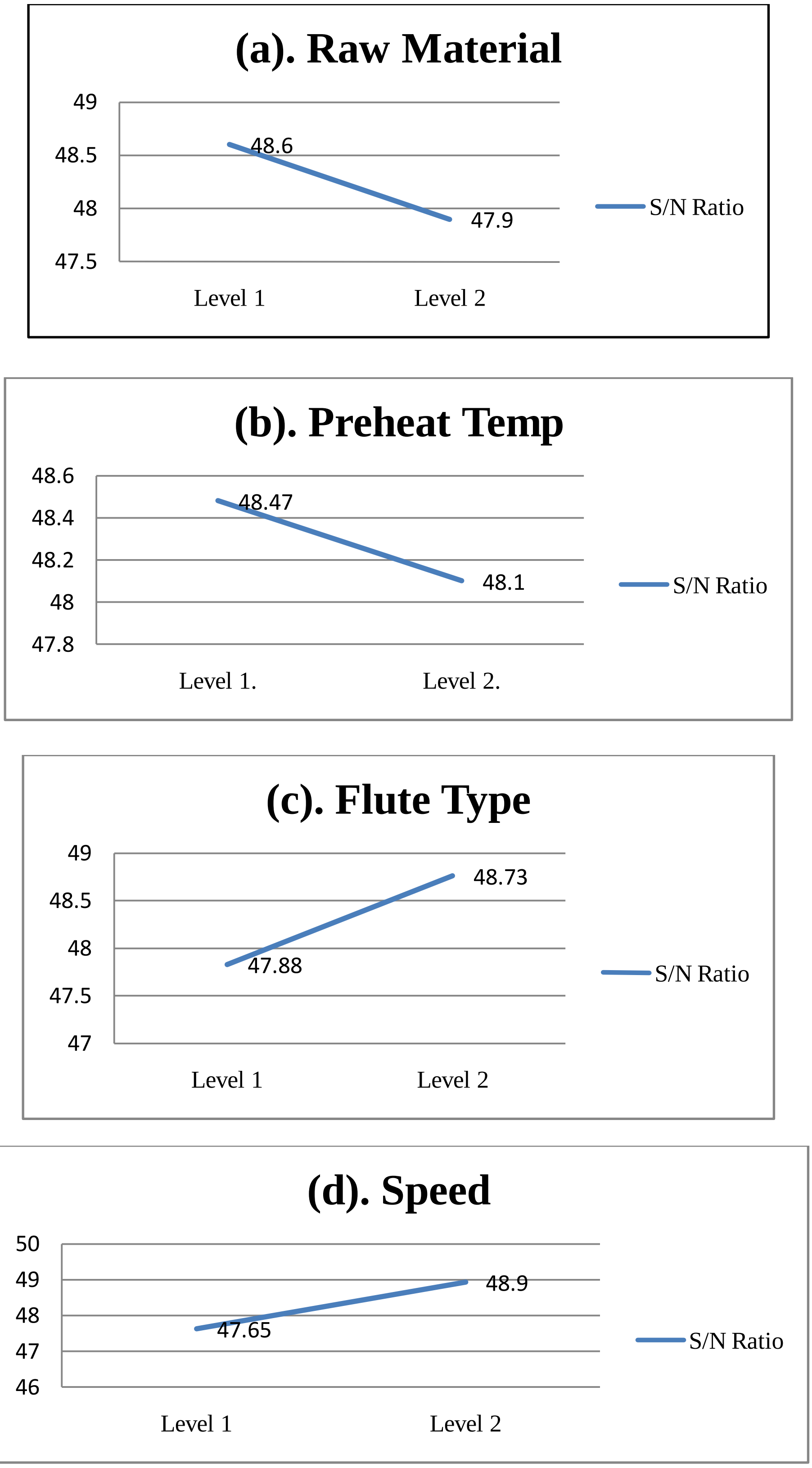
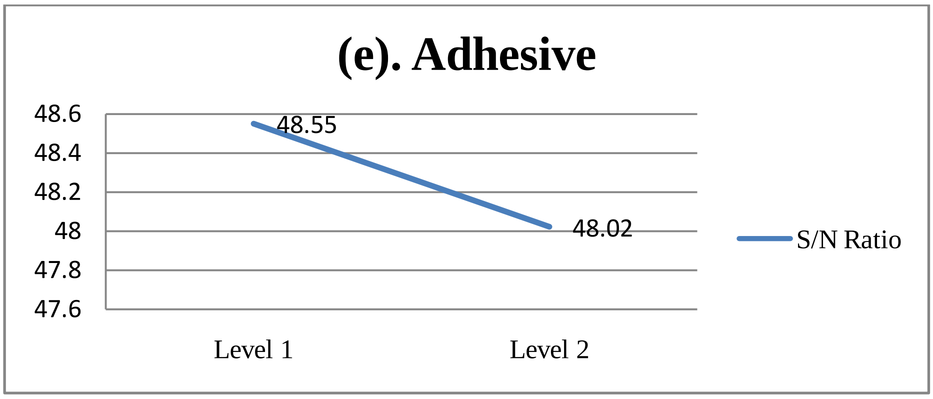
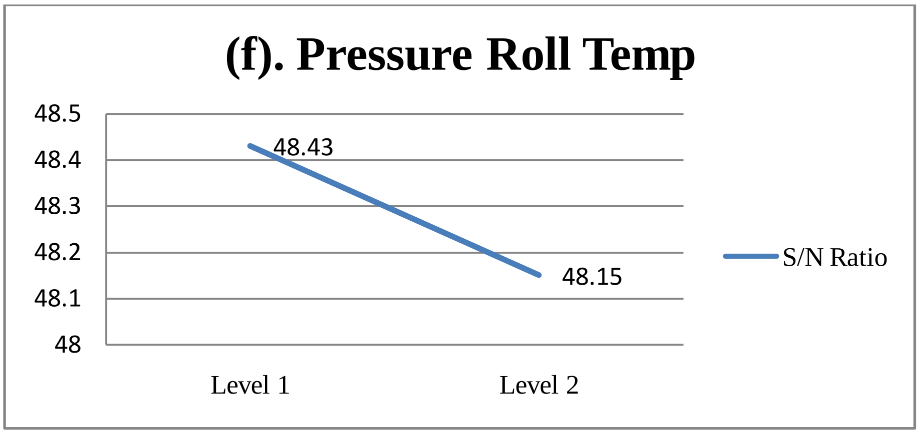
**FIG: 4.2 CHARTS SHOWING PARAMETER LEVEL V/S S/N RATIO**






(Source: Author's Data Analysis)

For calculating the "Production Rate" the objective function, "Larger the Better" type was used as shown.

$$\eta = -10 \log_{10} (_i^{2})/n)$$

The factor levels corresponding to the highest S/N ratio were chosen to optimize the condition. From these linear graphs it is clear that the optimum values of the factors and their levels are as given below.

**TABLE: 4.7 OPTIMUM VALUES OF FACTOR & THEIR LEVEL**

| Parameter | Optimum Value |
|---|---|
| Raw Material | Kraft Liner & Kraft Fluting Medium |
| Preheating Temp. | 192.2 C |
| Flute Type | Coarse Flute Type |
| Speed | 40 m/min |
| Adhesive | High Amylose Hybrid |
| Pressure Roll Temp. | 115 C |

(Source: Author Observation)

### 4.7.2 Average Effect of Factor Influence

It is important to study the How the factors behave? For Analysis of factor influence following calculation has been done by author.

T = (251+269.60+259.33+297.66+264.66+209.33+245+289.33)/8 = 260.74

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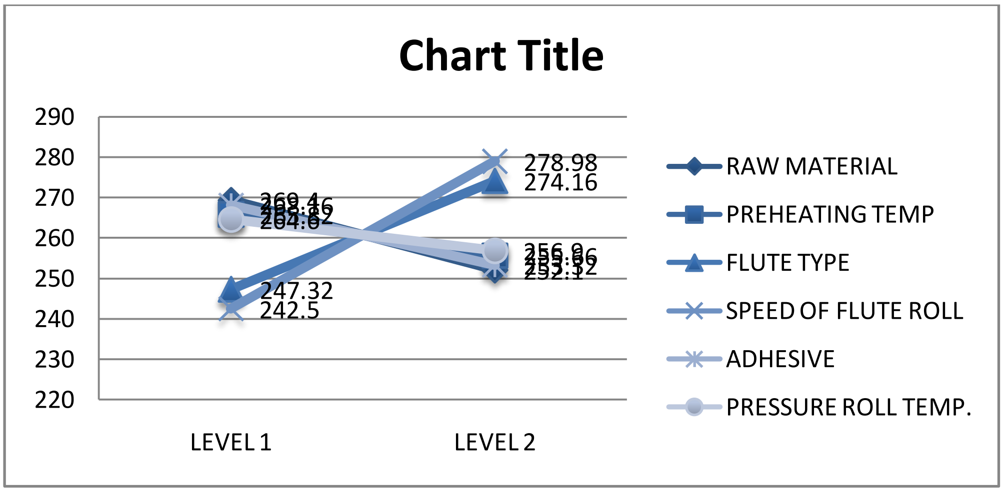
$A_1$ = (251+269.60+259.33+297.66)/4 = 269.39
$A_2$ = (264.66+209.33+245+289.33)/4 = 252.08
$\overline{B_1}$ = (251+269.6+297.66+245)/4 = 265.82
$\overline{B_2}$ = (259.33+264.66+209.33+289.33)/4 = 255.66
$\overline{C_1}$ = (251+259.33+269.6+209.33)/4 = 247.32
$\overline{C_2}$ = (297.66+264.66+245+289.33)/4 = 274.16
$\overline{D_1}$ = (251+264.66+209.33+245)/4 = 242.49
$\overline{D_2}$ = (269.6+259.33+297.66+289.33)/4 = 278.98
$\overline{E_1}$ = (251+259.33+297.66+264.66)/4 = 268.16
$\overline{E_2}$ = (269.6+209.33+245+289.33)/4 = 253.32
$\overline{F_1}$ = (251+297.66+264.66+245)/4 = 264.58
$\overline{F_2}$ = (269.6+259.33+209.33+289.33)/4 = 256.89

**FIG: 5.1 AVERAGE EFFECTS OF FACTOR INFLUENCE**




(Source: Author Observation)

**Performance Improvement:**

Improved performance from DOE = Estimated performance at the optimum condition ($Y_{opt}$)

$Y_{opt}$ = 297.66

The estimated performance can be expressed in terms of a percent improvement, if the current performance is known.

Assume that the current performance is the grand average of performance ($Y_{current}$) =264.66

**Improvement** = x 100

= x 100

= 12.5%

## 4.8 Confirmation Experiment

The following table 4.8 shows confirmation experiments conducted using Kraft liner & Kraft fluting medium type of raw material, 192.2$^0$C Temp. Of preheater, Coarse Flute type of corrugating roll, 40 m/min speed of Corrugating Roll, High Amylose Hybrid type of adhesive, & 115$^0$C Pressure Roll Temp. Total 3 set of experiments were conducted & their production rate were calculated. It can be seen that results are consistent.

**TABLE 4.8: CONFIRMATION EXPERIMENT**

| Experiment No. | Rate of Production (Output/Time) |
|---|---|
| 1. | 300 |
| 2 | 295 |
| 3 | 298 |
| Mean | 297.66 |

## V. COCLUSION

This Research Paper illustrates the application of the optimization technique (Taguchi Method) in Corrugation Packaging Industry to improve the Rate of Production. Following are the major outcomes of the present research:

- Taguchi Method of optimization result shows that Process Performance will depend upon the process parameters & their level. By optimizing control factors, production performance increase to its optimum level.
- Parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for optimizing the process parameters.
- Taguchi Method of parameter design can be performed with number of experimentations and yields results.

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