Process Improvement for PET Bottles Manufacturing Company Using Six Sigma Approach

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Abstract—Rejection in production processes cannot be ignored in industries in general, and in manufacturing organizations in particular. Six sigma has been considered an organized and scientific approach for the last few decades in order to reduce the number of rejections in processes. This paper has focused the injection modeling process in PET bottles manufacturing industry in Pakistan. The paper aims to reduce the number of rejected products produced during the injection molding process and highlight the significant factors and their level that severely affect the molding process. Different type of defects were observed in the injection molding process. Statistical approach using hypothetical analysis and experimental design techniques were used to conclude significant factors and their levels. Injection pressure, melting temperature, and resin type were observed as the most significant factors that affect the number of defective products produced during the PET bottles manufacturing. The joint interaction effect of pressure and temperature was also significant in comparison to all other interaction effects during this process.

Keywords—Six Sigma, Design of Experiment, Quality Control

I. INTRODUCTION

Six sigma has been considered as measure of quality in manufacturing and service industries for the last few decades. It is a disciplined and result oriented approach that eliminate defects by keeping the production or service processes near to the level of perfection. Linderman et al. define six sigma as “(…) an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates” [i]. The “sigma” terminology was introduced for the first time by Walter Shewhart in 1922 with the introduction of three standard deviations with mean. They highlighted that products falling outside the means, can be considered as defect[ii].

Six Sigma has been considered as customer-driven approach that eliminates waste, increase quality and improve organizational performance. Its main objective remain the identification of causes for poor performance or reduced productivity. Major causes are identified and preventive measure for process improvement are carried out in order to reduce defects and variations in processes. Although six sigma has been introduced and implemented in the manufacturing sector, however, it has also been common tool used in the service sector[iii]. The authors in [iv] highlighted the importance of Define-Measure-Analyze-Improve-Control (DMAIC) process based on potential parameters where the actual strength of this DMAIC process exists. They emphasized the fact that practitioner need to understand the strengths and limitations of the said six sigma problem solving approach. Six sigma is similar in functional approach as total quality management for solution of problems in manufacturing industries, such as PDCA i.e., Plan-Do-Check-Act and the Seven Step method of Juran and Gryna[v].

DMAIC can be considered as meta-routine in order to establish new routines by changing the existing ones[vi]. Six sigma has been basically applied to the generic situations in service and manufacturing processes to reduce variations in processes[vii]. Six sigma has been used as a basic for process improvement[viii]. Process can be considered as more consistent with greater number of sigma’s within the defined specification limits and reduced number of defects. It is not cost-effective to achieve six sigma level in all processes in an operation; therefore, one must focus on the most critical ones that are relevant to the customer requirements.

The PET bottles manufacturing process is also among those processes where tremendous improvements can be made in order to reduce defects produced in the process and increase company’s profits. Different approaches and techniques are applied to know the reasons behind the causes and significant
Two basic molding methods used for PET bottles, the one-step "hot preform" method and the two-step "cold preform" method. A two-step method has been used in the examined industry at industrial estate Hayatabad, Peshawar, KPK, Pakistan to produce PET bottles. The two-step method uses two separate machines. The first machine; an injection molding machine, injection molds the preform, which resembles a test tube, with the bottle-cap threads already molded into place. The body of the tube is significantly thicker, as it will be inflated into its final shape in the second step using stretch blow molding. In the second step, the blow molding machine reheats the preforms and is then inflated against a two-part mold to form them into the final shape of the bottle. This method is most suited in medium to large-scale production.

The generalized process of bottle manufacturing can be outlined as shown in Fig. 1. Dehumidifying drying agents are used for drying purposes before processing as PET may absorb moisture from the atmosphere. Dried PET pellets are then compressed and melted by a rotating screw. Molten PET is injected into the injection cavity and cooled rapidly to form a "Preform" (The test-tube-like cavity from which bottles are blown). The temperature of the preform is adjusted to the correct profile for blowing. The hot preform is simultaneously stretched and blown into a shaped blow mold to form a tough, lightweight container. The finished container is then ejected from the mold.

Polyethylene terephthalate commonly abbreviated as PET, is a thermoplastic polymer resin of the polyester family and is used in synthetic fibers such as beverage, food and other liquid containers, thermoforming applications, and engineering resins often in combination with glass fiber.

The majority of the world's PET production is for synthetic fibers around more than 60% with bottle production accounting for around 30% of global demand. Polyester makes up about 18% of world polymer production and is the third-most-produced polymer; polyethylene (PE) and polypropylene (PP) are first and second respectively. PET consists of polymerized units of the monomer ethylene terephthalate, with repeating C6H4O units. PET is commonly recycled and is referred as symbol number "1" for its recycling characteristics.

A. PET bottles manufacturing process

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The company produced PET bottles using two-step method including injection molding and blow molding processes. PET products produced during the processes results in rejection rate due to different types of defects. Quality control section of the company rejects these products due to these defects. It has been observed that the rejection rate is 11.24 preforms per hour in the injection molding process. These rejections have a significant impact on the medium range industry where financial impact rises up to 0.8 Million rupees per annum due to this process only. The management of the company is interested to reduce the number of rejected preforms produced in the process and increase company profits by reducing the associated loss. Technical personnel are focused to define major factors that affect the injection molding process and set levels of these factors such that the number of rejections are reduced.

C. 1) Process Flow Chart

Figure 2 shows the basic flow chart of the processes being carried out from raw material i.e., PET resins to the finished product i.e. PET bottles. The PET resins are received from the supplier and are then checked by the Quality Control (QC) department. If the resins are rejected by QC, they are returned to the supplier and if the resins are approved by QC, they are shifted to the raw material store. Then from the raw material store, these resins are issued to injection molding machines for perform production. There are two injection molding machines named as, Huskey’s machines (H-1 and H-2). H-1 machine has 48 cavities and produces perform of different weights such as (19, 25, 28, 39, 45, 48) gm. While H-2 has 96 cavities and produces perform of weights (17, 19, 25, 28, and 39) gm. After the production of perform, they are checked by the QC department. The rejected performs are sent to the crush unit for recycling and the approved performs are shifted to raw material store. After this, the approved performs are issued to the blow molding in order to produce PET bottles from the performs. PET bottles produced are checked by QC section. The rejected bottles are sent to the crush unit for recycling and the approved bottles are packed and kept in the store and are dispatched to the customers when orders
are received. The rejects from both injection molding and blow molding are sent to the crush unit for recycling and then the recycled material is issued to injection molding and the same process continues again and again.

Fig. 2. Flow chart PET bottles manufacturing process.
2) Types of defects

Defects were commonly observed in the injection molding process. The injection molding process was focused for further analysis to figure out significant factors that results in increased defect rate. Defects observed in the process could be in different forms. Major types have been listed below.

Fig. 3. Types of Defects in PET bottle production processes: (a) Short Shot (b) Flash on thread (c) Parting line flash (d) Long gate (e) Gate pin hole (f) Gate stringing (g) gate crystallization (h) moisture marks (i) air bubbles (j) Hazy Preform (k) Scratches.
II. STATISTICAL ANALYSIS AND DISCUSSION

Following factors have been identified in order to improve the process output.

1. Types of resin
2. Operator line
3. Melting temperature
4. Injection pressure

A. Significant factors identification

Following hypothesis are made in order to know whether these two levels of each factor are of significance.

H₀ = Variance of the two levels of each factor are equal.
H₁ = Variance of two levels of each factor are not equal.

An F-test is used to test if the variances of two samples are equal. This test can be a two-tailed test or a one-tailed test. The two-tailed version tests against the alternative that the variances are not equal. The one-tailed version only tests in one direction, that is the variance from the first sample is either greater than or less than the second sample variance.

Table II shows the results of the F-test conducted for the types of resin,

<table>
<thead>
<tr>
<th>Factors</th>
<th>Level 1</th>
<th>Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of resin</td>
<td>Type A (circular)</td>
<td>Type B (rectangular)</td>
</tr>
<tr>
<td>Operator line</td>
<td>Line 1</td>
<td>Line 2</td>
</tr>
<tr>
<td>Melting temperature</td>
<td>250°C</td>
<td>310°C</td>
</tr>
<tr>
<td>Injection pressure</td>
<td>40 Pa</td>
<td>70 Pa</td>
</tr>
</tbody>
</table>

Since the p-value = 0.025 < α = 0.05, therefore, the null hypothesis (H₀) is rejected in favor of the alternative hypothesis (H₁) and it is concluded that the variance for two types of resin is not equal. For the operator lines (L₁ and L₂)

B. Statistical Analysis and Discussion

Following factors have been identified in order to improve the process output.

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2. Operator line
3. Melting temperature
4. Injection pressure

Resin type were differentiated on the basis of shape and size i.e., circular (type A) and rectangular (type B). There were two injection molding machines in operation which were named as operator line 1; and operator line 2. As per the PET bottles manufacturing company common practices the acceptable range for the melting temperature is 250°C-310°C and for the injection pressure is 40 Pa-70 Pa. There were also some nuisance factors which are:

1. Moisture Content
2. Color of Preform

Above four factors were chosen for the experimentation purpose leaving the nuisance factors as the nuisance factors cannot be controlled in the given conditions. Data was collected as number of rejects per hour for each of the four factors, two different levels were selected for each factor as shown in Table I.

A sample of 100 hours data was collected at each level for all the factors. A normal probability plot of the residuals gives an indication of whether or not the assumption of the normality of the random errors is appropriate. A normal probability plot of the residuals is shown in Fig. 4, which shows that the normal probability plot is not far from the straight line which indicates that the normality assumption is satisfied for the data.

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Table III shows the results of the F-test conducted for the operator lines.

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Since the p-value = 0.025 < α = 0.05, therefore, the null hypothesis (H₀) is rejected in favor of the alternative hypothesis (H₁) and it is concluded that the variance for two types of resin is not equal. For the operator lines (L₁ and L₂)

Since the p-value = 0.0622 > α = 0.05, therefore, the null hypothesis H₀ cannot be rejected.
For melting temperatures

Since the \( p(F <= f) = 0.594 > \alpha = 0.05 \). The null hypothesis \( H_0 \) is true in this case, which means that the variance of the two levels of temperature is equal.

For low and high pressures

Since the \( p-value = 0.003 < \alpha = 0.05 \). Therefore, the null hypothesis can be rejected in favor of \( H_1 \) and concludes that the variance for two levels of injection pressure is not equal.

The t-test assesses whether the means of two samples are statistically different from each other. This analysis is appropriate whenever we want to compare the means of two samples.

T-test is performed for the data collected to know whether the means of the two levels of each factor are equal or not. For this, the null and the alternative hypotheses are stated as:

\[
H_0: \text{means are equal} \\
H_1: \text{means are not equal}
\]

We will reject the null hypothesis, if the p-value is less than or equal to level of significance (\( \alpha = 0.05 \)). Factors having p-value less than the level of significance \( \alpha \), will have a significant effect on the number of rejects.

For types of resin (A and B)

Table VI shows the difference in means and variance between the types of resin. It is based on hypothesis test since the p-value is less than alpha (\( \alpha \)) level of 0.05, i.e., \( P(T <= t) = 0.001 < \alpha = 0.05 \). Therefore, we reject the \( H_0 \), in favor of \( H_1 \), and conclude that the mean for two types of resin is not equal. Thus the inference from the hypothesis test is that there is a significant difference between the two types of resin and that contributes to the number of preform rejection rate.

For the operator lines (L1 and L2)

Table VII shows the difference in means and variance between the operator lines. It is based on hypothesis test since the p-value is greater than alpha (\( \alpha \)) level of 0.05, i.e., \( p(T <= t) = 0.057 > \alpha = 0.05 \). Therefore, fail in rejecting the null hypothesis \( H_0 \) and therefore the alternative hypothesis \( H_1 \) is rejected and concludes that the mean for two operator lines is equal. Thus the inference from the hypothesis test is that there is no significant difference between the two operator lines and that doesn't contribute much to the number of Preform rejects.
The t-test figure for the low and high pressures is given below:

Table IX shows the difference in means and variance between the two levels of injection pressure. It is based on hypothesis test since the p-value is less than alpha (α) level of 0.05, i.e. \( p(T \leq t) = 0.001 < \alpha = 0.05 \). So we reject the \( H_0 \), in favor of \( H_1 \), concludes that the mean for the two levels of injection pressure is not equal. Thus the inference from the Hypothesis test is that there is a significant difference between the two levels of injection pressure and that contributes to the number of Preform rejects.

From the F-test and t-test results, we have identified three controllable factors which are material, injection pressure and melting temperature. We took two levels of each of these factors and a full factorial experimental design was used and a total of 8 experimental runs were required. We made 8 replicates of each run, giving a total of 64 runs. Experimental design matrix was constructed, so that, when the experiment was conducted, the response values could be recorded on the matrix.

**TABLE VIII**

<table>
<thead>
<tr>
<th>Two-Sample T-Test and CI: Low Temperature, High Temperature</th>
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<tbody>
<tr>
<td>Two-Sample T for Low Temperature vs High Temperature</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Low Temperature</td>
</tr>
<tr>
<td>High Temperature</td>
</tr>
</tbody>
</table>

Difference = \( m_1 \) (Low Temperature) - \( m_2 \) (High Temperature)
Estimate for difference: 2.000
95% CI for difference: (0.537, 3.463)
T-Test of difference \( = 0 \) (vs not =): T-Value = 3.30 P-Value = 0.001 DF = 197

**TABLE IX**

<table>
<thead>
<tr>
<th>Two-Sample T-Test and CI: Low Pressure, High Pressure</th>
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<tbody>
<tr>
<td>Two-Sample T for Low Pressure vs High Pressure</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Low Pressure</td>
</tr>
<tr>
<td>High Pressure</td>
</tr>
</tbody>
</table>

Difference = \( m_1 \) (Low Pressure) - \( m_2 \) (High Pressure)
Estimate for difference: -1.60
95% CI for difference: [-2.750, -0.450]
T-Test of difference \( = 0 \) (vs not =): T-Value = 3.00 P-Value = 0.006 DF = 192

In the above matrix, \( A \) represents Material type, \( B \) represents injection pressure, \( C \) represents melting temperature, \( AB \) for the interaction effect of material type & injection pressure, \( AC \) for material type & melting temperature, \( BC \) for injection pressure & melting temperature and \( ABC \) for material type, injection pressure & melting temperature. Minus (-) sign represents the level 1 while plus (+) sign represents the level 2 of each factor.

In the first run we took material type A, injection pressure 40 Pa and melting temperature 250°C, and initiated the experiment. We collected the data as number of Preform rejects per hour and recorded on the matrix. We ran the same experiment 8 times and calculated the mean and standard deviation. Similarly in the next run, material type was changed to B while keeping the pressure and temperature the same. The same procedure was applied to all the possible combinations by changing the levels of factors to identify their effect on the response variable (number of Preform rejects). A more clear understanding of the data is illustrated from the cube plot of the data means.
TABLE XI

OPTIMAL CONDITIONS

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value/Type</th>
<th>Optimal Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET resin type</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>Melting temperature</td>
<td>310 °C</td>
<td>High(+)</td>
</tr>
<tr>
<td>Injection pressure</td>
<td>40 Pa</td>
<td>Low(-)</td>
</tr>
</tbody>
</table>

Given the above optimal conditions, the process was carried out for another 100 hours and the number of rejects reduced to an average of 3.750 rejects per hour from 11.24 rejects per hour.

V. CONCLUSIONS

The paper focused the injection molding process for PET bottles manufacturing in a selected company using six sigma approach. The rejection rate has been controlled significantly by highlighting significant factors statistically and set the optimum levels for the significant factors using experimental design approach. Hypothesis were made and analysis was performed based on F-test and t-tests to analyze the data variance and means. Statistical analysis showed that injection pressure, melting temperature, resin type and the interaction effect of pressure and temperature remain significant during the control of rejection rate in the processes. It was further shown that resin type B, high melting temperature, and low pressure resulted in reduced average number of rejections per hour. These optimal settings are strongly recommended for practitioners in the said field. The study was limited to the injection molding process in the PET bottles manufacturing process. The research finding are useful for PET bottles manufacturers especially for defect rate reduction. The methodology and sequence of tests used in this project can also be repeated for a specific type of rejects. For instance, the most common rejects in the selected industry was short shots so the whole projects can be repeated for this specific type of rejects. The research can be further extended to other relevant areas of manufacturing processes for process improvement.

REFERENCES


