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 factors that affect the process output. Application of these products are numerous and are extensively used in day-today life. 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 $C_{10}H_8O_4$ units. PET is commonly recycled and is referred as symbol number "1" for its recycling characteristics.

A. PET bottles manufacturing process

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.

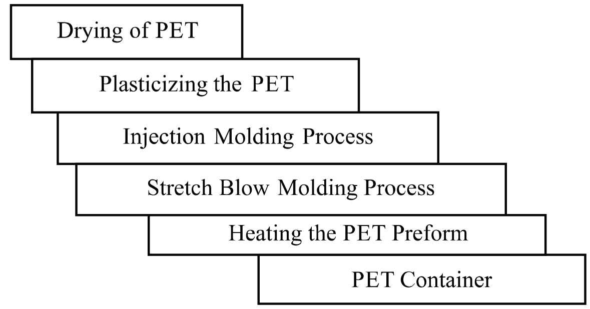

Fig. 1. Process flow diagram for PET bottles.

B. Problem formulation and process diagram

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.

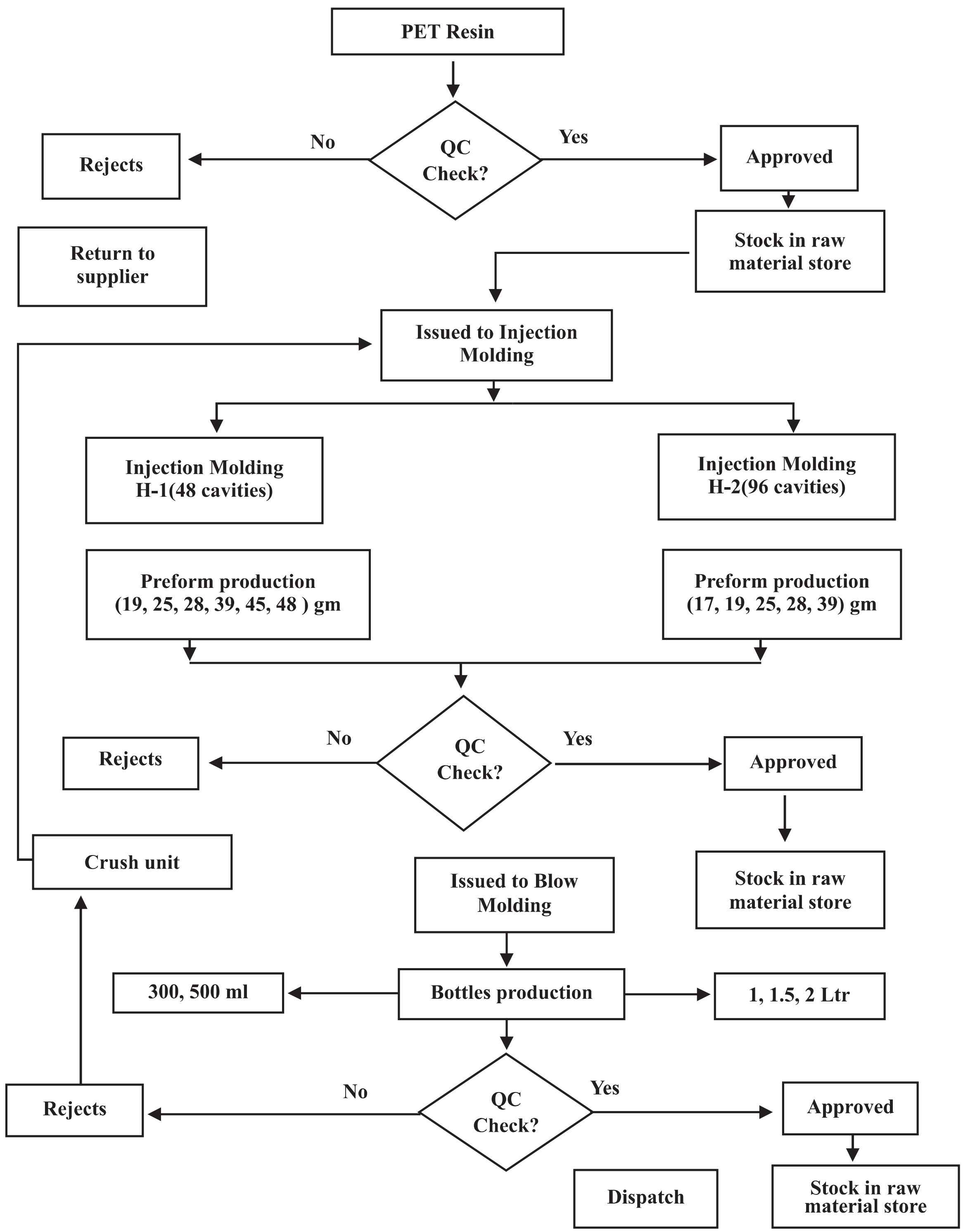

Fig. 2. Flow chart PET bottles manufacturing process.

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

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.

TABLE I
FACTORS LEVELS

Factors	Level 1	Level 2
Type of resin	Type A (circular)	Type B (rectangular)
Operator line	Line 1	Line 2
Melting temperature	250 C	310 C
Injection pressure	40 Pa	70 Pa

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.

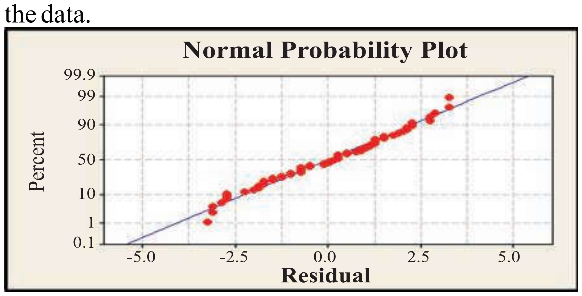

Fig. 4. Normal probability plot for residuals

A. Significant factors identification

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

Hypothesis are rejected based on P-value. Null hypothesis are rejected if the P-value is less than the level of significance. It is assumed that the level of significance (α) is taken as 5 %.

The null and the alternative hypotheses are stated as:

H_0 = Variance of the two levels of each factor are equal.
H_1 = 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 II
F-TEST FOR TYPES OF RESINS

Test and CI for Two Variances: Number of Defect in A, Number of Defect in B

```
Method

Null hypothesis         Sigma(Number of Defects in A per Hour) / Sigma(Number of Defects in B per Hour) = 1
Alternative hypothesis  Sigma(Number of Defects in A per Hour) / Sigma(Number of Defects in B per Hour) not = 1
Significance level      Alpha = 0.05


Statistics

Variable                          N  StDev  Variance
Number of Defects in A per Hour  25  4.173    17.417
Number of Defects in B per Hour  25  6.281    39.457

Distribution   CI for StDev      Variance
of Data           Ratio            Ratio
Normal        (0.441, 1.001)  (0.195, 1.002)
Continuous    (0.446, 1.035)  (0.199, 1.070)

                                          Test
Method                       DF1  DF2  Statistic  P-Value
F Test (normal)               24   24       0.44    0.025
```

Since the p-value= 0.025 < α=0.05, therefore, the Null hypothesis (H_0) is rejected in the favor of alternative hypothesis (H_1) and it is concluded that the variance for two types of resin is not equal. For the operator lines (L_1 and L_2)

TABLE III
F-TEST FOR OPERATOR LINES

Test and CI for Two Variances: Line 1, Line2

```
Method

Null hypothesis         Sigma(Line 1) / Sigma(Line2) = 1
Alternative hypothesis  Sigma(Line 1) / Sigma(Line2) not = 1
Significance level      Alpha = 0.05


Statistics

Variable    N  StDev  Variance
Line 1    100  4.266    18.196
Line2     100  3.653    13.344

Distribution   CI for StDev      Variance
of Data           Ratio            Ratio
Normal        (0.958, 1.424)  (0.917, 2.027)
Continuous    (0.937, 1.481)  (0.878, 2.192)

Method                       DF1  DF2  Statistic  P-Value
F Test (normal)               99   99       1.36   0.0622
```

Since the p-value = 0.0622 > α=0.05, therefore, the null hypothesis H_0 cannot be rejected.

For melting temperatures

Since the p(F<=f)= 0.594> α=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.

TABLE IV
F-TEST FOR MELTING TEMPERATURE

```
Test and CI for Two Variances: Low Temperature, High Temperature

Method

Null hypothesis         Sigma(Low Temperature) / Sigma(High Temperature) = 1
Alternative hypothesis  Sigma(Low Temperature) / Sigma(High Temperature) not = 1
Significance level      Alpha = 0.05


Statistics

Variable            N  StDev  Variance
Low Temperature   100  4.231    17.899
High Temperature  100  4.464    19.928

Distribution   CI for StDev     Variance
of Data           Ratio           Ratio
Normal       (0.777, 1.155)  (0.604, 1.335)
Continuous   (0.740, 1.138)  (0.547, 1.295)

Method                         DF1  DF2  Statistic  P-Value
F Test (normal)                 99   99       0.90    0.594
```

For low and high pressures

TABLE V
F-TEST FOR INJECTION PRESSURE

```
Test and CI for Two Variances: Low Pressure, High Pressure

Method

Null hypothesis         Sigma(Low Pressure) / Sigma(High Pressure) = 1
Alternative hypothesis  Sigma(Low Pressure) / Sigma(High Pressure) not = 1
Significance level      Alpha = 0.05


Statistics

Variable         N  StDev  Variance
Low Pressure   100  4.604    21.194
High Pressure  100  6.229    38.794

                                  CI for
Distribution   CI for StDev      Variance
of Data            Ratio           Ratio
Normal        (0.606, 0.901)  (0.368, 0.812)
Continuous    (0.640, 1.039)  (0.409, 1.079)

                                            Test
Method                         DF1  DF2  Statistic  P-Value
F Test (normal)                 99   99       0.55    0.003
```

Since the p-value = 0.003< α=0.05. Therefore, the null hypothesis can be rejected in the 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= means are equal

H_1= means are not equal

We will reject the null hypothesis, if the p-value is less than or equal to level of significance (α=0.05).

Factors having p-value less than the level of significance α, will be having 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 (α) level of 0.05, i.e., P(T<=t)= 0.001 < α=0.05. Therefore, we reject the H_0 in the 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 (L_1 and L_2)

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 α (0.05), i.e. p(T<=t)= 0.057 > α=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 contributes much to the number of Preform rejects.

TABLE VI
T-TEST FOR TYPES OF RESIN

```
Two-Sample T-Test and CI: Number of Defects in A p, Number of Defects in B p

Two-sample T for Number of Defects in A per Hour vs Number of Defects in B per
   Hour
                        N   Mean  StDev  SE Mean
Number of Defects in A p  25   6.80   4.17     0.83
Number of Defects in B p  25  12.04   6.28      1.3

Difference = mu (Number of Defects in A per Hour) - mu (Number of Defects in B
   per Hour)
Estimate for difference:  -5.24
95% CI for difference:  (-8.27, -2.21)
T-Test of difference = 0 (vs not =): T-Value = -3.47  P-Value = 0.001  DF = 48
```

TABLE VII
T-TEST FOR OPERATOR LINES

```
Two-Sample T-Test and CI: Line 1, Line2

Two-sample T for Line 1 vs Line2

          N   Mean  StDev  SE Mean
Line 1  100   9.92   4.27     0.43
Line2   100  11.36   3.65     0.37


Difference = mu (Line 1) - mu (Line2)
Estimate for difference:  -1.440
95% CI for difference:  (-2.548, -0.332)
T-Test of difference = 0 (vs not =): T-Value = -2.56  P-Value = 0.057  DF = 193
```

For melting temperatures

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

For low and high pressures

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. $p(T<=t)= 0.001 < \alpha=0.05$. So we reject the H_0 in the favor of H_{1} and 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
T-TEST FOR TYPES OF MELTING TEMPERATURE

```
Two-Sample T-Test and CI: Low Temperature, High Temperature

Two-sample T for Low Temperature vs High Temperature

                    N   Mean  StDev  SE Mean
Low Temperature   100  12.00   4.23     0.42
High Temperature  100   9.97   4.46     0.45


Difference = mu (Low Temperature) - mu (High Temperature)
Estimate for difference:  2.030
95% CI for difference:  (0.817, 3.243)
T-Test of difference = 0 (vs not =): T-Value = 3.30  P-Value = 0.001  DF = 197
```

TABLE IX
T-TEST FOR INJECTION PRESSURE

```
Two-Sample T-Test and CI: Low Pressure, High Pressure

Two-sample T for Low Pressure vs High Pressure

                 N   Mean  StDev  SE Mean
Low Pressure   100  12.28   4.60     0.46
High Pressure  100  15.56   6.23     0.62


Difference = mu (Low Pressure) - mu (High Pressure)
Estimate for difference:  -3.280
95% CI for difference:  (-4.808, -1.752)
T-Test of difference = 0 (vs not =): T-Value = -4.23  P-Value = 0.001  DF = 182
```

TABLE X
MATRIX FOR DOE RUNS

Run#	Run Order	A	B	C	D-AB	E-AC	F-BC	G-ABC	R1	R2	R3	R4	R5	R6	R7	R8	Ave.	Std.Dev.
1	1	-	-	-	+	+	+	-	12	18	17	12	15	16	16	15	15.1	2.17
2	2	+	-	-	-	-	+	+	10	11	12	8	9	12	10	14	10.8	1.91
3	3	-	+	-	-	+	-	+	21	19	18	22	23	24	21	18	20.8	2.25
4	4	+	+	-	+	-	-	-	16	18	16	19	18	17	17	19	17.5	1.20
5	5	-	-	+	+	-	-	+	6	8	7	8	5	7	6	9	7.0	1.31
6	6	+	-	+	-	+	-	-	4	5	6	4	3	3	3	2	3.8	1.28
7	7	-	+	+	-	-	+	-	14	18	15	17	19	19	15	18	16.9	1.96
8	8	+	+	+	+	+	+	+	9	14	10	13	12	10	14	8	11.3	2.31

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.

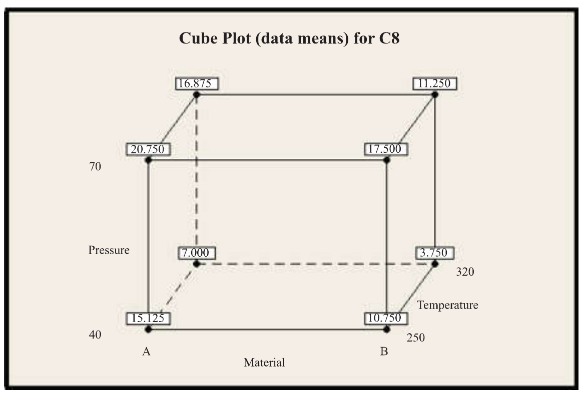

Fig. 5. Cube plot of the data means

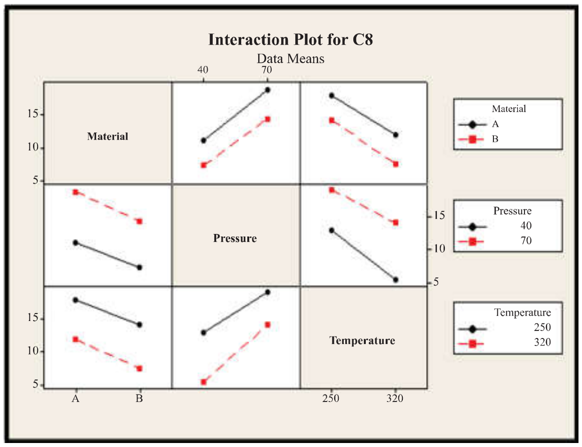

Fig. 6. Interaction plot for the significant factors.

The cube plot in Fig. 5, represents the mean values of the interactive effects at different levels of each factor from the data collected by conducting the DOE runs. The lowest value i.e. 3.750 rejects per hour observed at combination of Material type B, injection pressure 40 Pa and melting temperature 320°C which means that this is the optimal condition for the lowest number of Preform rejects.

The interaction plot Fig. 6, highlights the fact that strong interaction among the three factors does not exist in the given levels. Similar kind of analysis can be observed in the Pareto chart shown in Fig. 7.

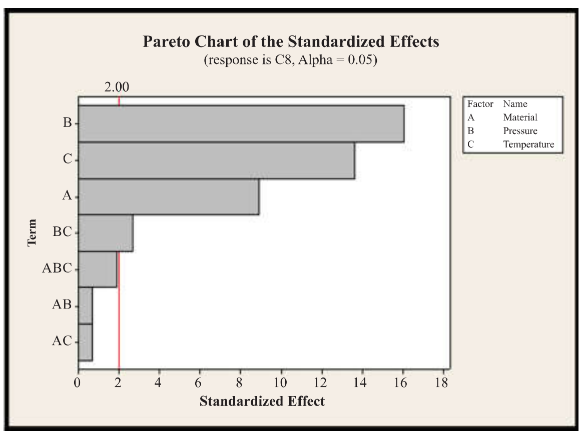

Fig. 7. Pareto chart for the standardized effects of factors.

The Pareto chart in Fig. 7 shows that the most significant factors and interacting are B, C, A, and BC respectively. Other interaction factors can be considered as non-significant. Therefore, the optimal conditions are as under

TABLE XI
OPTIMAL CONDITIONS

Factor	Value/Type	Optimal Setting
PET resin type	B	B
Melting temperature	310 °C	High(+)
Injection pressure	40 Pa	Low(-)

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.

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