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Aspen D'Costa
Southern Illinois University Carbondale, aspen@siu.edu

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Additional Information

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CHARACTERIZATION OF KEY PROCESS PARAMETERS IN INJECTION BLOW MOLDING FOR IMPROVING QUALITY

Submitted by

Aspen D'Costa
Southern Illinois University, Carbondale

Abstract

The purpose of this study was to discover the performance of significant process parameters in manufacturing 20 oz. plastic beverage bottles. An experimental methodology was carefully designed to examine the characteristics of key variables such as ambient and operating temperatures, process line operators, resin types, resin colors and operating lines associated with a plastic bottle manufacturing line. More explicitly, this study seeks to identify the definitive relationship between the selected process parameters for the production machine (Sidel™) and the ensuing product quality. Also, this study was conducted to evaluate the performance characteristics of Post Consumer Resin (PCR), virgin resin and the diverse variations within them.

Introduction

About 1.5 million barrels of oil, which is sufficient for almost 100,000 cars to run for a year, are used in the production of plastic water bottles alone. Adding to this, the consumption of additional fossil fuels used to engender the electricity fuelling the manufacturing process produces global warming pollution into the atmosphere (Union of Concerned Scientists, 2007). The growth in the amount of water bottles sold has increased approximately five fold between 1997 and 2002 (Llanos, 2005, pp. 1), depicting the increased usage of plastic bottles and blow molding. Mainly industries would like to be as cost-effective as possible, particularly with energy consumption and would like to use the most resourceful blow molding process applicable to them.

Inconsistencies with process control procedures prevail within the Injection Blow Molding industry and despite extensive research there exists vagueness about the appropriate methodology to be utilized. A process with uncontrolled variability can lead to losses, such as energy wastes.

Statement of the Problem

The predicament identified by Acme Bottling Company (an alias established for the propriety protection of the actual Midwest blow molding company), that the Post Consumer Resin (PCR) caused increased defects compared to the virgin grade of resin. During initial observation, there were inconsistencies in setting the set point temperature (operating temperature) for a particular preform temperature (ambient temperature) for the bottles. The operators, who relied on a trial and error method, made judgment calls in order to set the operating temperature. There was a deficiency of a standard operating procedure for making process adjustments to improve quality.

Purpose of the Study

The purpose of this study is to identify the key process parameters used for manufacturing 20 oz. plastic beverage bottles. More explicitly, this study seeks to identify the definitive relationship between process parameters for the production machine and the ensuing product quality. The findings of this research are used to make process control recommendations.

Significance of the Study

The study is designed to gain insight into the injection blow molding process and lay a foundation for future studies at Acme Bottling (AB) Company that will lead to gains in productivity and quality. The rationale of this study is to evaluate the characteristics between PCR and virgin resin and all its variations. The identification of the interactive nature, between process variables such as operating lines, temperatures, resin colors (PCR & virgin) and process operators need to be analyzed. It is hoped that this research will lead to cost savings in the manufacturing process, conserving energy and aid in utilizing PCR extensively which will abet the recycling process.

Research Questions

1. Does PCR produce the same product quality as virgin preforms?

This research, attempts to answer this by analyzing various bottle runs and observing the defects occurring for all resins and their color subcategories. The independent and the dependent variables are the Resin type (PCR, Virgin) and the product quality respectively.

2. Is there a significant correlation between preform temperature and product quality?

By recording the respective preform temperature and verifying it with Pearson's coefficient analysis, a correlation could be established. The independent and dependent variable in this experiment would be the preform temperature and the product quality respectively.

3. Is there a significant correlation between operating temperature and product quality?

By recording the respective setpoint temperature and verifying it with Pearson's coefficient analysis, a correlation could be established. The independent and dependent variable in this experiment would be the operating temperature and the product quality respectively.

4. What are the statistical (2 sample t-test,F-test, Pearson's correlation Analysis, Regression Analysis) significances of process variables such as operating lines, colors, resin types and process operators on product quality?

Production process data will be analyzed using a variety of statistical techniques such as 2 sample t-test, F-test, Pearson's correlation Analysis, Regression Analysis to determine each variable's impact. The independent variables used here are the operating lines, colors, resin types, process operators and the dependent variables are product quality respectively.

History of Bottles

Around 1500 B.C, the Egyptians were the first to create glass bottles by placing molten glass around a core of sand and clay. After this process was completed, the core was removed and the glass cooled. The method of making bottles was prolonged and complex, so they were considered an opulent item in ancient Egypt. The next evolution in glass making was found in China and Persia in 200 B.C. using a method whereby molten glass was blown into a mold. Shortly thereafter, the Romans adopted this similar method which gained popularity all through Europe during the 1400s and 1500s.

The earliest bottle and glass-making factory in the United States was established in Virginia in 1608. The nineteenth century designates an innovative epoch in the variations of glass bottle making. The first patented baby bottle originated in 1841. The famous Mason jar with a screw-on cap was invented in 1858. The pressing and blowing machine enabled the bottle-making process to become automated in 1865, but was oriented to produce limited varieties. Also, during the mid-1800s, Dr. Hervey Thatcher devised the glass milk bottle. The first soda pop bottle was introduced in 1915 by the Coca-Cola Company. A unique shape of a bottle was followed by several other brands.

Company names and logos came into prominence after 1934 when Soda bottle shapes were standardized and technology enabled companies to fire permanent color onto bottles (Wikipedia, 2007).

Until 1903, fully automated machines for making various types of glass bottles and jars did not originate; however, it made its appearance when a man named Michael J. Owens put the Owens Bottle Machine into commercial use. This Machine enabled the economical, large-scale production of glass bottles. The large-scale carbonated beverage industry was propelled by the inception of the Crown bottle cap. Most glass bottles were modeled after Owens' invention by the 1920's. Twenty years later, plastic bottles were manufactured using the blow molding process. The first plastic bottle for carbonated beverages was brought forth by Andrew Wyth through the Du Pont Corporation (Bryk, 2007, pp. 1).

Relevant to this analysis is Post Consumer Resin (PCR), which is an amalgamation of a HDPE (High Density Polyethylene) and virgin resin. Optimal resin blend composition can lead to extensive use of recycled resins in making plastic bottles (Awaja, et al., 2005). PCR is economical, easily processed and also aids the environment by utilizing recycled plastic. The recycled material is cleaned, ground and recompounded into pellets along with primary virgin material which is further on used to make PCR. Injection blow molding, the least commonly used process among all the molding processes, is often used to make single serve bottles like the 20 oz. bottles used in this study. Injection blow molding is complex and the performance of the bottles is directly related with the processing parameters like operating and preform temperatures and also blowing pressure (Schmidt et al., 1988).

Significance of Energy Consumption

The broader outlook of this study would be to save on energy consumption. AB Company would like to be as economical as they can be with their electricity. Injection blow molding process is an energy intensive process and having better process control could add to the revenues of the industry.

Most of the energy in this process is dispensed in heating the bottles, where high wattage lamps (1000 watts) consume large amounts of electricity and also compressors that inject the compressed air in the bottles. Reports state, "The electricity price increase would be 10 percent for residential customers, more for commercial customers. Commercial customers such as retail stores would pay 23 percent more and larger industrial customers would pay 29 percent more" (Southeast Missourian State, 2006). This concern was voiced by AB Company, one of the many affected consumers of increased power rates by Ameren™, who are also the electricity suppliers for industries around Missouri and Southern Illinois. Since scrap or defective bottles cannot be reworked (segregation and melting) in AB Company and has to be transported to Iowa, which is at a considerable distance from the manufacturing facility, it is all the more important that wastage be reduced by improving process set-ups (Zagarola, 2000).

Interviews

In order to gather ample information regarding the blow molding operation, interviews were conducted with a few manufacturing industry professionals from AB

Company. The people who were interviewed were mostly shift operators and the maintenance supervisor. In an attempt to provide anonymity, names have been excluded.

First Interview

During the interview, it was explained by John Doe (Maintenance Supervisor) that the process was difficult to stabilize. A measure of consistency would be tricky to achieve and this response was common with all the shift operators who felt the same way (AB Company, Personal communication, May 15th, 2007). The supervisor also affirmed with the trial and error method which is expensive and time consuming was widely used to improve the Injection Blow molding process (Yin, et al., 2005).

Second Interview

The second interview was conducted with the plant manager, Marilyn Moe. She provided overhead expenditures and how difficult it was to keep up with the rising costs for power. She also agreed that the best operating conditions are met by optimizing the manufacturing process parameters (Tanhoub, et al., 2004). She showed optimism and welcomed change for the better, which is an important attitude while leading an organization (AB Company, Personal communication, May 15th, 2007).

Third Interview

The third interview was with the Quality manager, Cameron Poe, and he showed great faith in improving the facility. He identified the resin to be the problematic issue as he explains, “The manufacturers never provide a consistent resin and it keeps changing” (AB Company, Personal communication, May 15th, 2007). He also said that the data (resin type, operating temperature and all other variables) were recorded but not preserved for more than 2 weeks; thus, wasting collected information. He also concurs with the interactive nature of the process variables and wants to implement a strategy to deal with the key variables (Zagarola, 1997). He says that preform and storage temperature affects the final product quality (Rujnic-Sokele, et al., 2004).

Interview Conclusions

Identifying the key independent variables associated with the process and their signifying role could contribute to a consistent operation in AB Company. The personal interviews and article reviews have surprising revelations which include the following:

- The data and results of operation are not stored or analyzed for achieving consistency.

- Research has identified that experienced employees make judgment calls when setting the set point temperature. Significant inconsistencies exist among industry professionals about what general guidelines to use (Zagarola, 2000).

There was consensus on solving the issue and, although skepticisms existed, everyone contributed relevant information.

RESEARCH METHODS

The purpose of this study was to identify the impact of the key independent variables and utilize them for manufacturing, 20 oz. plastic beverage bottles. An experimental methodology was carefully designed to analyze the characteristics of key variables such as ambient and operating temperatures, process line operators, resin types and operating lines associated with a plastic bottle manufacturing process. This study seeks to identify the statistical relationship between process parameters for the production machine (Sidel™) and the resulting product quality. Also, this study was conducted to compare the statistical significance between Post Consumer Resin (PCR) and all its sub-categories such as the various colored bottles within them. Similarly the investigation for the virgin grade resin and all colored bottles formed using virgin resin.

Manufacturing Process

The apparatus used for this study is the blow molding injection machine manufactured by Sidel™, which is widely available around the world and is used extensively among many of the world's plastic bottle manufacturers. The machine contains heat lamps, sensors, a conveyor line, vision system and an injection mold.

Fig.1 Blow Mold Injection Machine[1]

As seen above in Fig.1, there is a conveyor line which feeds the preforms into the heating process, where they are heated by a series of high wattage lamps. The preforms are then passed into the blow mold stage, where they are suspended by the neck while being injected with compressed air by a nozzle expanding bottles into their final shape. The preform and the set point temperatures are measured via infrared sensors and are shown on the display screen for adjustment.

After the bottles are completely formed, the process of elimination begins. The bottles are inspected by a vision system which compares each bottle with the given specifications from the pre-loaded parameters and a high resolution image shows the defects in the bottle. If they are determined defective, the bottles are automatically segregated out of the machine. From there, the defective bottles are crushed and sent for melting and, thus, go through the process all over again. The vision system software interfacing along with the computer touch pad screen enables the whole manufacturing

[1] Image retrieved from www.sidel.com

process to be completely automated, which also allows for minimal intervention during operation. It shows all the developments in the machine and also allows the operator to monitor the temperature and manually change the specifications.

Process Design

The study was performed in the manufacturing facility of AB Company Corporation, Marion, Illinois. The predicament recognized by AB Company was that the PCR resin was utilizing augmented heat compared to the virgin grade of resin. The identification of key variables was conducted, through a brainstorming session with the employees of AB Company and a spreadsheet was prepared, to clearly depict the key variables during the manufacturing process. The information for the spreadsheet was gathered by the process operator monitoring the bottle runs and key variables such as the operating lines, set point and preform temperatures and resin types were recorded. Shift times, the amount of preforms fed in the injection blow molding machine, the resulting bottles and the process operator were also recorded in the spreadsheet. The information would be gathered for a period of two months. A sample size of about 250 million bottles, for all the uniquely different resins will be analyzed with a batch size approximately varying from 15000 to 160000 bottles.

Independent Variable

The independent variables chosen for this study are resin types, set point, preform temperatures, colors, process operators, and the production lines.

RESIN TYPE (R_n): The resins are assumed to play a significant role in determining the outcome of the bottle, as each resin is made of a different chemical composition and, thus, the bottle resulting is usually different. This study mainly focuses on two resin manufacturers, Novopak™ and Ball Containers™. The different diversifications in the resins of study contrast from PCR to virgin and are further classified on the basis of their chemical composition.

SET POINT TEMPERATURE (T_S): This is assumed to play a pertinent role in the study, because it determines whether the injection blow molding machine is drawing augmented power. Also, surplus or lesser amounts of heat can cause significant damage to the bottles' quality. In this experiment, the operating temperature is called the set point temperature and this is adjusted to heat the preforms in the oven.

PREFORM TEMPERATURE (T_P): This is the temperature recorded for the preform by the sensor in the blow molding injection machine, prior to undergoing the blow molding process. Preform temperature here in this experiment is regarded as the ambient temperature. The interactive nature between the set point temperature and the preform temperature is also studied in this experiment.

RESIN COLORS (R_c): The colors used for this experiments range from transparent (clear), green and blue. The statistical significance for each of the resin colors will be evaluated.

PROCESS OPERATORS (P_o): There are 14 operators whose effect on the overall manufacturing process is considered for this study. However, the batch size of the bottles for each operator varied from 15,000 to 160,000 approximately.

PRODUCTION LINE (L_1 & L_2): The batch of bottles produced on line no. 1 is compared to line no. 2. Analysis observes existing differences in the operating parameters as well as the resulting product quality.

Dependent Variable (Q)

The dependent variable in our analysis is the quality of the bottle, which is defined as a bottle independent of lack of holes, cracks, thin walls and weak bases.

Analysis Procedure

The purpose of the study was to formulate a measure of consistent operation to the whole process, since no previous research had been conducted by AB Company. A description of steps necessary to perform the study was developed. It is as follows:

1) Without interrupting the production process, data was collected for a period of two months. A sample size of a total of 250 million bottles for PCR and virgin grades of resins were run through the Injection Blow Molding process.
2) The measurement process is done via the computer touch pad screen where all the relevant data is observed, stored and recorded in the data collection sheet. The relevant data for the study is collected at the end of each manufacturing run, by the respective operator for a particular batch of bottles.
3) After the data is gathered, sort the raw data accordingly on the basis of resin type (color, chemical composition of the resin) and operating lines in a Microsoft Excel® spreadsheet.

4) Identify the operating lines, operators and the resin types where the maximum defects occur at a particular set point temperature for the corresponding preform temperature.
5) Analyze the deviation and the interactiveness if any, among the independent variables associated with manufacturing the bottles using statistical procedures.
6) The analysis plan is conducted via a 2 sample T-Test assuming unequal variances, with MINITAB™ statistical software for the hypothesis analysis at a critical value of 0.05.

Ex:

H_0: $\mu_1 = \mu_2$ where μ_1 and μ_2 are the % average defects for PCR and virgin respectively.

H_1: $\mu_1 \neq \mu_2$ where μ_1 and μ_2 are the % average defects for PCR and virgin respectively.

7) Perform a 2 sample T-Test assuming unequal variances, for comparing the effectiveness of the independent variables like resin colors and operating lines with the same hypothesis as above while changing the value of μ_1.& μ_2 .
8) Conduct an F-Test for unequal variances between % PCR and Virgin defects with MINITAB™, the operating lines and the various resin colors.

Ex:

H_0 : $\sigma^2_1 = \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % PCR and Virgin defects.

H_1 : $\sigma^2_1 \neq \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % PCR and Virgin defects.

9) Perform a 2 sample F-Test assuming unequal variances, for comparing the effectiveness of the independent variables like resin colors and operating lines with the same hypothesis as above while changing the value of $\sigma^2{}_1$.& $\sigma^2{}_2$.

10) Process all the independent variables into scatter and probability plots to verify that the data assumes normality.

11) Perform a correlation analysis between the defects and the independent variables and observe the Pearson's coefficient of correlation for all the independent variables.

12) Plot histograms for the characteristics of preform, set point temperatures, resin types, colors, operators, and the production lines.

13) Perform a regression analysis to verify which independent variable has the most effect on the process.

Assumptions

The following assumptions were made during the course and completion of this study:

- No previous in-depth research has been conducted and applied to the Injection Blow Molding Industry.
- There is potential for energy savings when producing bottles from either grade of plastic (PCR & Virgin).
- The chemical composition of a particular resin should be consistent.

Scope and Limitations

This research needs more in-depth analysis of the chemistry of the resin and consistent resin chemistry is also assumed, but not verified.

ANALYSIS OF DATA

The data generated during this research has been evaluated using the statistical analysis software package in Excel® from Microsoft Office and MINITAB™. The T-Test: Two Sample Assuming Unequal Variances was selected as the analytical methodology for comparing all the variables. The 2 sample F-Test for Equal Variances was also conducted to find out which variable had the most positive or negative effect on the process. Additionally Histogram plots, Correlations and Regression analysis were conducted.

Research data

Tables 1 through 18 present the analysis of the raw data which were most critical to the research. The tables contain results from T and F-Tests. A two sample T-Test between the independent variables and its sub-categories was performed to determine whether there was a significant difference between them, at a critical alpha (α) level of .05. The F-Test analyzes the variability within the key independent variables or provides a measure of probability whether they have the same variance also, at a critical alpha (α) level of .05. The regression analysis is further conducted to find the effect each key independent variable has on the process. The Pearson's Correlation Coefficient Test is used to analyze whether there was measure of association between independent variables. The difference in sample sizes (N) for the bottles while comparing independent variables, depended upon Crisp Container's production demand

and could not be specified by the researcher. However, the sample sizes are sufficiently large to accurately estimate the true percent average defect.

PCR vs. VIRGIN:

These tests examines for the first research question whether there was any statistically significant difference in the production output when the two different resins, virgin and PCR were used.

Two-Sample T-Test and CI: % PCR defects vs. % Virgin defects

A Two-Sample T-Test between virgin and PCR is performed to determine whether there was any significant difference between the resins at a critical alpha (α) level of 0.05. Table 1 shows information about the sample number used for analysis "N", the mean and the standard deviation.

Table 1. T-Test results for % PCR defects vs. % Virgin defects

RESIN TYPE	N	Mean	St.Dev
% PCR DEFECTS	174935	2.47	3.28
%VIRGIN DEFECTS	107314	4.04	7.17

Difference = μ_1 (% PCR DEFECTS) - μ_2 (% VIRGIN DEFECTS)

H_0: $\mu_1 = \mu_2$ where μ_1 and μ_2 are the % average defects for PCR and virgin respectively.

H_1: $\mu_1 \neq \mu_2$ where μ_1 and μ_2 are the % average defects for PCR and virgin respectively.

T-Test of difference = 0 (vs. not =): T-Value = -1.43; p-value = 0.158; DF = 54

Interpretation: The Table 1 shows that the means are comparatively close and since the p-value is greater than the critical alpha (α) level of .05, the alternative hypothesis is rejected and there is failure to reject the null hypothesis. Therefore there is no significant difference in the resins when compared through their means.

Test for Equal Variances (F-Test): % PCR defects vs. % Virgin defects

The F-Test analyzes the variances for the two resins, virgin and PCR. Using 95% Bonferroni confidence intervals for standard deviations, the F-Test analyzes "N" number of bottle samples and determines the standard deviation and the maximum and minimum (Upper and Lower) among the percentage defective values.

Table 2. F- Test results for % PCR defects vs. % Virgin defects

RESIN TYPE	N	Lower	St. Dev	Upper
% PCR DEFECTS	174935	2.83	3.28	3.88
% VIRGIN DEFECTS	107314	5.80	7.16	9.31

$H_0 : \sigma^2_1 = \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % PCR and Virgin defects.

$H_1 : \sigma^2_1 \neq \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % PCR and Virgin defects.

F-Test (Normal Distribution): Test statistic = 0.21, p-value = 0.000

Interpretation: The result in Table 2 shows that PCR and virgin resins have significantly different standard deviations. Also, outliers exist in both the processes mainly due to uncontrolled process parameters. Based on the hypothesis test there is failure in rejecting the null hypothesis, that the variances of the virgin and PCR are dissimilar, because the determined p-value is less than the chosen critical alpha value of 0.05.

OPERATING LINE 1 vs. OPERATING LINE 2:

These tests examine for the third research question whether there exists a considerable impact from the process variables on the injection blow molding process. In this analysis, the impact of the 2 operating lines is verified by comparing the defects caused on each line, through descriptive statistic tests (F & T-test).

Two-Sample T-Test and CI: Line 1 vs. Line 2

A Two-Sample T-Test between operating Line 1 and operating Line 2 is performed to determine whether there was any significant difference between the resins at a critical alpha (α) level of 0.05. Table 3 shows information about the bottle sample number used for analysis "N", the mean and the standard deviation. The hypothesis tested here are for the percentage defects between the operating lines 1&2. The null hypothesis states that the operating lines are similar and the alternative hypothesis contradicts the null hypothesis. In the MINITAB™ test, Line 2 has been denoted with the "-1" and Line 1 with "1".

Table 3. T-Test results for Line 1 vs. Line 2

LINES	N	Mean	St.Dev
Line2 (-1)	132544	2.38	3.87
Line 1 (1)	174935	3.61	5.75

Difference = μ_1 (-1) - μ_2 (1)

H_0: $\mu_1 = \mu_2$ where μ_1 and μ_2 are the means of the % average defects for Line 1 and Line 2 respectively.

H_1: $\mu_1 \neq \mu_2$ where μ_1 and μ_2 are the means of the % average defects for Line 1 and Line 2 respectively.

T-Test of difference = 0 (vs. not=): T-Value= -1.53; p-value=0.129; DF = 120

Interpretation: Table 3 shows that the operating lines are fairly similar when compared through their means and the standard deviations are not far apart from each other. The alternative hypothesis is rejected and there is failure in rejecting the null hypothesis, because the p-value is greater than the chosen critical alpha (α) value of 0.05. The hypothesis infers that no statistically significant difference exists between the means of the operating lines.

Test for Equal Variances (F-Test): Line 1 vs. Line 2

The F-Test is used to compare the variances of the operating lines. Using 95% Bonferroni confidence intervals for standard deviations the F-Test analyzes "N" number of bottle samples and determines the standard deviation and the maximum and minimum (Upper and Lower) among the percentage defective values. In the MINITAB™ test Line 2 has been denoted with the "-1" and Line 1 with "1".

Table 4.F-Test results for Line 1 vs. Line 2

LINES	N	Lower	St.Dev	Upper
Line 2 (-1)	132544	3.27	3.86	4.69
Line 1 (1)	149705	4.83	5.74	7.07

$H_0 : \sigma^2_1 = \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % defects on Line 1 and Line 2 respectively.

$H_1 : \sigma^2_1 \neq \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % defects on Line 1 and Line 2 respectively.

F-Test (Normal Distribution): Test statistic = 0.45, p-value = 0.001

Interpretation: The observation made through Table 4 is that the standard deviations are relatively close. According to the hypothesis test, the null hypothesis is rejected and there is failure in rejecting the alternative hypothesis, as the p-value is less than the chosen critical alpha (α) value of 0.05. This means that operating Line 1 has increased variability compared to operating Line 2, when their respective variances are compared.

VIRGIN GREEN vs. VIRGIN CLEAR:

These tests examine for the third research question whether the process variables changes considerably, having a statistically significant effect on the injection blow molding process. In this analysis, the impact of the colors is verified by comparing the defects caused by green and clear virgin resin colors, through descriptive statistic tests (F & T-test).

Two-Sample T-Test and CI: Virgin Green vs. Virgin Clear

A Two-Sample T-Test between colors green and clear (transparent) is performed to determine whether there is any significant difference between the resin colors at a critical alpha (α) level of 0.05. Table 5 shows information about the bottle sample number used for analysis "N", the mean and the standard deviation. The hypothesis tested here is for the percentage defects between the colors green and clear among virgin resin. The null hypothesis states the colors are similar and the alternative hypothesis contradicts the null hypothesis. In the following MINITAB™ test the color green has been denoted with "-1" and clear with "1".

Table 5. T-Test results for Virgin Green vs. Virgin Clear

COLOR	N	Mean	St.Dev
GREEN (-1)	22969	2.36	2.33
CLEAR(1)	250375	3.03	4.46

Difference = μ_1 (-1) - μ_2 (1)

H_0: $\mu_1 = \mu_2$ where μ_1 and μ_2 are the means of the % average defects for colors green and clear virgin resins respectively.

H_1: $\mu_1 \neq \mu_2$ where μ_1 and μ_2 are the means of the % average defects for colors green and clear virgin resins respectively.

T-Test of difference = 0 (vs. not =): T-Value = -0.60; p-value = 0.555; DF = 20

Interpretation: Table 5 shows that the two resins are fairly similar when compared through their means. The alternative hypothesis is rejected as the p-value is greater than the chosen critical alpha (α) level of 0.05. Based on the hypothesis test, the inference is that there is not a considerable amount of difference between the amounts of defects caused by the two colors.

Test for Equal Variances (F-Test): Virgin Green vs. Virgin Clear

The F-Test analyzes the variances between the colors green and clear among the virgin resins. Using 95% Bonferroni confidence intervals for standard deviations the F-Test analyzes "N" number of bottle samples and determines the standard deviation and the maximum and minimum (Upper and Lower) among the percentage defective values. In the following MINITAB™ test the color green has been denoted with "-1" and clear with "1".

Table 6. F-Test results for Virgin Green vs. Virgin Clear

COLORS	N	Lower	St.Dev	Upper
GREEN (-1)	22969	1.46	2.33	5.34
CLEAR(1)	250375	3.50	4.45	6.08

H_0 : $\sigma^2_1 = \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % defects of green and clear colored virgin resins respectively.

H_1 : $\sigma^2_1 \neq \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % defects of the green and clear colored virgin resins respectively.

F-Test (Normal Distribution): Test statistic = 0.27, p-value = 0.080

Interpretation: Table 6 shows the distinction between the colors standard deviation not too far apart. Through the hypothesis test, there is failure in rejecting the null hypothesis as the p-value is greater than the chosen critical alpha (α) value of 0.05.

The inference through this test is that no statistically significant difference exists between the two colors, green and clear. The amounts of defects caused between the virgin colors, green and clear are more or less similar.

VIRGIN BLUE vs. VIRGIN CLEAR:

These tests examine for the third research question whether the process variables changes considerably, having a statistically significant effect on the injection blow molding process. In this analysis, the impact of the colors is verified by comparing the defects caused by blue and clear virgin resin colors, through descriptive statistic tests (F & T-test).

Two-Sample T-Test and CI: Virgin blue vs. Virgin clear

A Two-Sample T-Test between colors green and clear (transparent) is performed to determine whether there is any significant difference between the resin colors at a critical alpha (α) level of 0.05. Table 7 shows information about the bottle sample number used for analysis "N", the mean and the standard deviation. The hypothesis tested here are for the percentage defects between colors blue and clear among the virgin resins. The null hypothesis states the colors are similar and the alternative hypothesis contradicts the null hypothesis. In the following MINITAB™ test the color blue has been denoted with "0" and clear with "1".

Table 7. T-Test results for Virgin Blue vs. Virgin Clear

COLOR	N	Mean	St.Dev
BLUE(0)	8905	16.23	18.26
CLEAR(1)	250375	3.09	4.46

Difference = μ_1 (0) - μ_2 (1)

H_0: $\mu_1 = \mu_2$ where μ_1 and μ_2 are the means of the % average defects for colors blue and clear virgin resins respectively.

H_1: $\mu_1 \neq \mu_2$ where μ_1 and μ_2 are the means of the % average defects for colors green and clear virgin resins respectively.

T-Test of difference = 0 (vs. not =): T-Value = 1.43; P-Value = 0.247; DF = 3

Interpretation: In Table 7 the observation is that the means of the colors are far apart and so are the standard deviations. The alternative hypothesis is rejected because the p-value is greater than the chosen critical alpha (α) level of 0.05.

Thus, the inference based on the hypothesis test is that there are increased defects caused with the color blue, compared to clear among the virgin resins.

Test for Equal Variances (F-Test): Virgin Blue vs. Virgin Clear

The F-Test analyzes the variances between the colors blue and clear among the virgin resins. Using 95% Bonferroni confidence intervals for standard deviations the F-Test analyzes "N" number of bottle samples and determines the standard deviation and the maximum and minimum (Upper and Lower) among the percentage defective values. In the following test the color blue has been denoted with "0" and clear with "1".

Table 8. F-Test results for Virgin Blue vs. Virgin Clear

COLOR	N	Lower	St.Dev	Upper
BLUE(0)	8905	9.58	18.24	86.38
CLEAR(1)	250375	3.50	4.45	6.08

$H_0 : \sigma^2_1 = \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % defects of colors blue and clear virgin resins respectively.

$H_1 : \sigma^2_1 \neq \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % defects of colors blue and clear virgin resins respectively.

F-Test (Normal Distribution): Test statistic = 16.73, p-value = 0.000

Interpretation: Table 8 shows that the standard deviations are far apart. According to the hypothesis test, the null hypothesis is rejected and there is failure in rejecting the alternative hypothesis, as the p- value is less than the chosen critical alpha (α) value of 0.05. The hypothesis test infers that the resins are not similar and the color blue causes increased amount of defects when compared to clear.

VIRGIN GREEN vs. VIRGIN BLUE:

These tests examine for the third research question whether the process variables changes considerably, having a statistically significant effect on the injection blow molding process. In this analysis, the impact of the colors is verified by comparing the defects caused by green and blue virgin resin colors, through descriptive statistic tests (F & T-test).

Two-Sample T-Test and CI: Virgin Green vs. Virgin Blue

A Two-Sample T-Test between colors green and blue is performed to determine whether there is any significant difference between the resin colors at a critical alpha (α) level of 0.05. Table 9 shows information about the sample number used for analysis "N", the mean and the standard deviation. The hypothesis tested here are for the percentage defects between colors green and blue among the virgin resins. The null hypothesis states the colors are similar and the alternative hypothesis states that they are opposite. In the following MINITAB™ test the color green has been denoted with "-1" and blue with "0".

Table 9. T-Test results for Virgin Green vs. Virgin Blue

COLOR	N	Mean	St.Dev
GREEN (-1)	22969	2.36	2.33
BLUE (0)	8905	16.2	18.20

Difference = μ_1 (-1) - μ_2 (0)

H_0: $\mu_1 = \mu_2$ where μ_1 and μ_2 are the means of the % average defects of colors green and blue virgin resins respectively.

H_1: $\mu_1 \neq \mu_2$ where μ_1 and μ_2 are the means of the % average defects of colors green and blue virgin resins respectively.

T-Test of difference = 0 (vs. not =): T-Value = -1.51; P-Value = 0.227; DF = 3

Interpretations: Table 9 shows the existing difference between the standard deviation between standard deviations and means. Also based on the hypothesis test, there is failure in rejecting the null hypothesis, as the p-value is greater than the chosen critical alpha (α) value of 0.05. Thus, the inference is that not a statistically significant difference exists between the two colors, green and blue and the defects caused between them.

Test for Equal Variances (F-Test): Virgin Green vs. Virgin Blue

The F-Test analyzes the variances between the colors green and blue among the virgin resins. Using 95% Bonferroni confidence intervals for standard deviations the F-Test analyzes "N" number of samples and determines the standard deviation and the maximum and minimum (Upper and Lower) among the percentage defective values. In the following MINITAB™ test the color blue has been denoted with "0" and green with "-1".

Table 10. F-Test results for Virgin Green vs. Virgin Blue

COLOR	N	Lower	St.Dev	Upper
GREEN(-1)	22969	1.46	2.33	5.34
BLUE (0)	8905	9.58	18.24	86.38

$H_0 : \sigma^2_1 = \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % defects of colors green and blue virgin resins respectively.

$H_1 : \sigma^2_1 \neq \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % defects of colors green and blue virgin resins respectively.

F-Test (Normal Distribution): Test statistic = 0.02, p-value = 0.000

Interpretations: Table 10 shows the standard deviations to be far apart. Based on the hypothesis test, we reject the null hypothesis and there is failure in rejecting the alternative hypothesis, as the p-value is less than the chosen critical alpha (α) value of

0.05. This means that there is increased number of defects caused in the color blue compared to green among the virgin resins.

PCR GREEN vs. PCR CLEAR:

These tests examine for the third research question whether the process variables changes considerably, having a statistically significant effect on the injection blow molding process. In this analysis, the impact of the colors is verified by comparing the defects caused by green and clear PCR colors, through descriptive statistic tests (F & T-test).

Two-Sample T-Test and CI: PCR Green vs. PCR Clear

A Two-Sample T-Test between colors green and clear is performed to determine whether there is any significant difference between the resin colors at a critical alpha (α) level of 0.05. Table 11 shows information about the bottle sample number used for analysis "N", the mean and the standard deviation. The hypothesis tested here are for the percentage defects between colors clear and green among the PCR resins. The null hypothesis states the colors are similar and the alternative hypothesis states that they are opposite. In the following MINITAB™ test the color clear has been denoted with "-1" and green with "1".

Table 11. T-Test results for PCR Green vs. PCR Clear

COLOR	N	Mean	St.Dev
CLEAR(-1)	250375	2.28	2.62
GREEN(1)	22969	4.50	7.29

Difference = μ_1 (-1) - μ_2 (1)

H_0: $\mu_1 = \mu_2$ where μ_1 and μ_2 are the means of the % average defects of colors clear and green PCR respectively.

H_1: $\mu_1 \neq \mu_2$ where μ_1 and μ_2 are the means of the % average of colors clear and green PCR respectively.

T-Test of difference = 0 (vs. not =): T-Value = -0.91; P-Value = 0.390; DF = 8

Interpretation: Table 11 shows the existing difference in the means and standard deviation between the colors. Also, based on the hypothesis test, there is failure in rejecting the null hypothesis and the alternative is rejected as the p-value is greater than the chosen critical alpha (α) level of 0.05. Thus, the inference from the hypothesis test is that there is no statistically significant difference between the two resins and the amount of defects caused between them are more or less similar.

Test for Equal Variances (F-Test): PCR Green vs. PCR Clear

The F-Test analyzes the variances between the colors green and blue among the virgin resins. Using 95% Bonferroni confidence intervals for standard deviations the F-Test analyzes "N" number of bottle samples and determines the standard deviation and the maximum and minimum(Upper and Lower) among the percentage defective values. In the following MINITAB™ test the color clear has been denoted with "-1" and green with "1".

Table 12. F-Test results for PCR Green vs. PCR Clear

COLOR	N	Lower	St.Dev	Upper
CLEAR(-1)	250375	2.24	2.61	3.12
GREEN(1)	22969	4.66	7.28	15.53

$H_0 : \sigma^2_1 = \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % defects of colors clear and green PCR respectively.

$H_1 : \sigma^2_1 \neq \sigma^2_2$ where σ^2_1 and σ^2_2 are the variances of the % defects of colors clear and green PCR respectively.

F-Test (Normal Distribution): Test statistic = 0.13, p-value = 0.000

Interpretation: Table 12 shows the existing difference between the standard deviations. According to the hypothesis we reject the null hypothesis and there is failure in rejecting the alternative hypothesis, as the p-value is less than the chosen critical alpha (α) value of 0.05. Thus the inference from the hypothesis is that the resins, green and clear, among the PCR are not similar and green causes increased number of defects compared to clear.

Regression Analysis

In the following analysis the key independent variables are analyzed against the percentage defects. This aids observation simplicity as the predictors or independent variables are all viewed together. The significance of any impact on the process is analyzed between the key independent variables. The regression equation calculates the total percentage defects caused by each of the independent variables.

The regression equation is given by

PCR % Defects+Virgin % Defects = 12.9 + 0.058 Resin Type + 0.581 Operating Line1+Operating Line2 - 1.23 Resin Colors - 0.149 Set point temperature (PCR+virgin) + 0.069 Preform temp. (PCR+virgin)

Table 13 calculates the p-value for all the predictors and the T-statistic value.

Table 13. Regression test results

Predictor	Coef.	SE Coef.	T	P
Constant	12.864	9.709	1.32	.187
RESIN TYPE	0.0584	.6205	.09	.925
LINES1+2	0.5806	.459	1.26	.208
Colors	-1.2348	.6692	-1.85	.067
Set pt. temp.(pcr+virg)	-0.1491	.152	-.98	.328
Preform temp.(pcr+virg)	0.0686	.1471	.47	.642

S = 4.77291; R-Sq = 7.0%; R-Sq (adj) = 3.8%

Interpretation: Table 13 shows all the predictors regressed to get the resulting T and p-value. Based on the p-values, the inference made is that the colors have the most significant impact on the process and the others do not have a numerically significant impact. The R-Sq value indicates that the key independent variables have accounted for just 7% of the process variables and infers that there still include 93% unexplained process variability.

Table 14 and Table 16 analyze the regression sum of squares and mean of squares to find the respective F and p-value.

Table 14. Analysis of Variance

Source	DF	SS	MS	F	P
Regression	5	248.47	49.69	2.18	0.059
Residual Error	145	3303.19	22.78		
Total	150	3551.66			

Table 16. Predictor's individual Sum of Squares

Source	DF	Seq SS
RESIN TYPE	1	79.36
LINES1+2	1	37.86
colors	1	101.59
set pt. temp.(pcr+virg)	1	24.70
preform temp.(pcr+virg)	1	4.95

Interpretation: In Table 15 the F-value is obtained from the ratio of the mean of squares and table 16 depicts the individual sum of squares for each predictor.

Pearson's Correlation Analysis

Pearson's correlation values show the correlation of each key process variable on the blow molding injection process.

Table 18. Correlation Comparisons

CORRELATION TYPES	PEARSONS CORRELATION VALUE

%PCR DEFECTS vs. PCR COLOR	.191
%PCR DEFECTS vs. %VIRGIN DEFECTS	.149
LINE1 vs. LINE2	.127
%DEFECTS vs. PCR+VIRGIN SET PT. TEMPERATURE	-.21
%DEFECTS vs. PCR SET PT. TEMPERATURE	-.147
%DEFECTS vs. PCR+VIRGIN PREFORM TEMPERATURE	-.177
%DEFECTS vs. PCR PREFORM TEMP.	-.182
%DEFECTS vs. VIRGIN SET PT. TEMPERATURE	-.203
%DEFECTS vs. VIRGIN PREFORM TEMP.	-.028

Interpretation: No significant correlation can be obtained for the analyzed process variables through the Pearson's correlation comparison.

A Summary of all the T and the F-Tests are given in Table 19

Table 19. Summary

COMPARISONS	T-TEST RESULT	F-TEST RESULT

PCR vs. Virgin	No Significant Difference	More Variability exists in resin type Virgin
Line 1 vs. Line 2	No Significant Difference	More Variability exists in operating Line 1
Virgin Green vs. Virgin Clear	No Significant Difference	No Significant Difference
Virgin Blue vs. Virgin Clear	No Significant Difference	More Variability exists in color Blue
Virgin Green vs.Virgin Blue	No Significant Difference	More Variability exists in color Blue
PCR Green vs. PCR Clear	No Significant Difference	More Variability exists in color Green

Process Operators Defects:

In Table 20, individual process or shift operator's cumulative average defects are analyzed. The cumulative average % defect is calculated by aggregating all the defects each process operator is responsible for each batch of bottles produced.

Table 20. Process operator Cumulative defects

PROCESS OPERATORS(P_o)	CUMULATIVE AVERAGE % DEFECT

OPERATOR A	1.40
OPERATOR B	1.64
OPERATOR C	3.53
OPERATOR D	4.67
OPERATOR E	1.74
OPERATOR F	0.59
OPERATOR G	9.49
OPERATOR H	5.68
OPERATOR I	13.11
OPERATOR J	1.58
OPERATOR K	1.50
OPERATOR L	4.41
OPERATOR M	3.87
OPERATOR N	3.96

Interpretation: Through Table 20 the observation is that Operator I is responsible for 13.11% defects which is the highest while operating the process and Operator F has the least amount of defects with .59%. Operators, who are highlighted, have an insufficient sample size of bottles worked upon. Their efficiency cannot be solely based on these results.

CONCLUSIONS AND RECOMMENDATIONS

In this thesis, the relationships between the key independent variables on the injection blow molding process are explored. The variables included are preform, set point temperatures, resin types, colors, process operators and the production lines. An analysis of the percentage defects or dependent variables has been performed for uniquely different resins. The analysis compared the independent and dependent variables, using the T-test and the F-test assuming a critical α- value of 0.05. There was also analysis utilizing regression methods and Pearson's correlation.

Interpretation of Observations

In chapter one, the first research question posed, "Does PCR produce the same product quality as virgin preforms?" Significant difference exists in variability between PCR and virgin resin. This is observed through Observation #1.

Observation #1: Answers to Research Questions 1,2 & 3

The first observation compared the PCR and the virgin grade of resins using the T-test; the alternative hypothesis was rejected because the p-value was greater than our confidence interval value of .05. Also, illustrated in APPENDIX C, Fig. 1c, the observation made is that more variability exists with the virgin grade of resin compared to PCR. The statistical observation contradicts AB Company claims of more variability in the PCR compared to the virgin resin.

Variability in this context would mean increased defects within PCR compared to virgin resin.

Research Question 2 asks, “Is there a significant correlation between the preform temperature and product quality?” This question is answered through the use of descriptive statistics in Table 13 & 18. Based on the regression analysis, there is no significant impact made by the preform temperatures to the blow molding injection process. This is also confirmed by the Pearson’s correlation analysis. The feasible range of preform temperatures can be observed in APPENDIX B, Fig’s. 9b through 17b, where it shows the accepted production level for minimal defects.

Research Question 3 asks, “Is there a significant correlation between the setpoint temperature and product quality?” This question is answered by observing the values obtained in Table 13 & 18. Pearson’s correlation corroborates this by depicting the correlation being not significant enough. The feasible range of setpoint temperatures can be observed in APPENDIX B, Fig’s. 9b through 17b, where it shows the accepted production level for minimal defects.

Observation #2: Answers to Research Question 4

No remarkable correlation can be obtained for the analyzed process variables through the Pearson’s correlation comparisons.

The final research question asked “What effect do the process variables such as preform, set point temperatures, operating lines, resin types and process operators have on the product quality?” In order to answer this question, statistical data representing comparisons for the key independent variables must be interpreted individually from Observation #3 through Observation #10.

Observation #3

The third observation, which measured quality on a particular operating line, was conducted using a T-test which yielded the following results in Table 4. There was failure in rejecting the null hypothesis stating that there was not a significant difference in their means. The F-test shows that there was a statistically significant difference in the variability of Line No. 1 compared to Line No. 2 as shown in Table 3 and APPENDIX C, Fig. 2c. The hypothesis testing for the variance corroborates the existing variability.

Observation #4

The fourth observation compared the color green and clear among the virgin resins and the inference made was that the color green among the virgin resins has increased variability when compared to clear resin as observed in APPENDIX C, Fig. 3c. In the T-test, we rejected the alternative hypothesis as the p-value is greater than .05 stating that the resins are similar. In the F-Test we rejected the alternative hypothesis concluding that the defects among the resins were fairly similar. The similarity between the resins is confirmed by APPENDIX, Fig 3c which shows the variance in the box plot to be identical.

Observation #5

The fifth observation compared color blue among the virgin resins to the clear resin and the inference made is that blue has more statistical significant difference in the variability, as seen through the box plot in APPENDIX C, Fig. 4c. The T-test rejects the alternative hypothesis and states there is not a significant amount of difference in their means. The F-Test states that there is failure in rejecting the alternative hypothesis, stating that there exists increased variability in the color blue compared to clear.

Observation #6

The sixth observation compared colors blue and green among the virgin resins and the Box Plot in APPENDIX C, Fig. 5c shows that more variability exists in the color blue compared to green. The T-test states there is failure in rejecting the null hypothesis, thus stating they are fairly similar. The F-Test states that there is failure in rejecting the alternative hypothesis, concluding that there exists increased variability in the blue virgin resin.

Observation #7

The seventh observation compared colors green and clear among the PCR and the observation made is that green has more deviation compared to the clear resin. The box plot in APPENDIX C, Fig. 6c shows that greater variability exists in the color green. The T-test shows that there is not a significant difference between the two grades of resins and the alternative hypothesis was rejected. The F-Test shows that there is a statistically significant difference in the variability between the colors and thus, the null hypothesis is rejected accordingly.

Observation #8

The observation made through the regression analysis measured the effect of key independent variables on the blow molding injection process. Also, the total defects could be mathematically quantified through the regression equation, where all the independent variables are taken into consideration, including the preform and set point temperatures. The regression method concludes that the independent variables are more or less significant to the blow molding injection process and there is also 93% unexplained process variability as the R-Sq value is just 7%.

Observation #10

The observation made for the process operators was that most of them had significant amount of % defects. These could be attributed to lack of adequate time on the equipment and formal training. With a guideline to follow, operator efficiency can be better realized. There are also cases, where the operators were responsible for a smaller batch size of bottles, and because of insufficient sample size it would be unjustified to term them as inefficient. This is also better explained by observing the Pareto chart, Fig. 22b where the data is represented in descending order.

Conclusions

This research found that a statistically significant difference exists in variability between PCR and virgin resin. Also, no significant correlation exists between the preform variable, setpoint temperature and product quality. A feasible range of setpoint and preform temperatures for producing minimal defects can be observed in APPENDIX B, through Fig's. 9b to17b. Process operators can employ the range of suitable temperatures to reduce the amount of defects. Finally, resin type, operating line and resin color have been found to have a statistically significant impact on the variability in injection blow molding process, which is summarized in Table 19.

Recommendations for Future Work

- Conduct a Six Sigma study to identify causes of variability and improve process consistency.
- Evaluate the chemistry of the resin to ensure that specifications are being met.
- Conduct a Design of Experiments to determine other processing parameters that significantly impact product quality.
- Develop standard operating procedures to improve process consistency.
- Measure process parameters that have a significant effect on energy consumption.

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APPENDIX A

Table 1:

LINE	BOTTLES IN	BOTTLES OUT	% DEFECT(Q)	DEFECTS	RESIN(PCR/VIRGIN)	RESIN IDENTITY
2	5362	4110	23.34949646	1252	PCR GREEN BALL	RO7T40/R19T2 1
2	47092	43948	6.676293213	3144	PCR GREEN BALL	RO7T40/R19T2 1
2	55846	54722	2.012677721	1124	PCR GREEN BALL	RO7T40/R19T2 1
2	14709	14415	1.998776259	294	PCR GREEN BALL	RO7T40/R19T2 1
2	14343	14200	0.997002022	143	PCR GREEN BALL	RO7T40/R19T2 1
2	14574	14284	1.989844929	290	PCR GREEN BALL	RO7T40/R19T2 4
2	14862	14713	1.002556856	149	PCR GREEN BALL	RO7T40/R19T2 1
2	15248	15096	0.996852046	152	PCR GREEN BALL	RO7T40/R19T2 1
2	94056	92678	1.46508463	1378	PCR GREEN BALL	RO7T40/R19T2 1

Table 1 continued:

SET PT.(T_S)	PREFORM TEMP.(T_p)	% ACCEPTANCE	OPERATOR(P_o)
113	110	76.650504	OPERATOR D
112	112	93.323707	OPERATOR D
112	110	97.987322	OPERATOR D
113	112.6	98.001224	OPERATOR C
113	111.8	99.002998	OPERATOR C
106	110.5	98.010155	OPERATOR C
116	113.7	98.997443	OPERATOR C
116	114.4	99.003148	OPERATOR C
112	112	98.534915	OPERATOR D

Table 2:

LINE	BOTTLES IN	BOTTLES OUT	% DEFECT(Q)	DEFECTS	RESIN(PCR/VIRGIN)	RESIN IDENTITY

1	11594	10601	8.564774884	993	PCR BALL CLEAR	RO7T40T21
1	70171	68215	2.787476308	1956	PCR BALL CLEAR	RO7T40T21
1	11635	11519	0.996991835	116	PCR BALL CLEAR	RO7T40T21
1	11748	11630	1.004426285	118	PCR BALL CLEAR	RO7T40T21
1	11683	11566	1.001455106	117	PCR BALL CLEAR	RO7T40T21
1	31738	27577	13.11046695	4161	PCR BALL CLEAR	RO7T40T21
1	68784	68198	0.851942312	586	PCR BALL CLEAR	RO7T40T21
1	109455	109284	0.156228587	171	PCR BALL CLEAR	RO7T40T21
1	79266	76825	3.079504453	2441	PCR BALL CLEAR	RO7T40T21
1	113936	110769	2.77963067	3167	PCR BALL CLEAR	RO7T40T21
1	59670	57142	4.236634825	2528	PCR BALL CLEAR	RO7T40T21
1	99511	95570	3.960366191	3941	PCR BALL CLEAR	RO7T40T21
1	85940	82502	4.000465441	3438	PCR BALL CLEAR	RO7T40T21
1	164171	163062	0.675515164	1109	PCR BALL CLEAR	RO7T40T21
1	73988	72192	2.427420663	1796	PCR BALL CLEAR	RO7T40T21
1	139948	137503	1.747077486	2445	PCR BALL CLEAR	RO7T40T21
1	11752	11634	1.004084411	118	PCR BALL CLEAR	RO7T40T21
1	68027	67219	1.187763682	808	PCR BALL CLEAR	RO7T40T21
1	136960	135609	0.986419393	1351	PCR BALL CLEAR	RO7T40T21
1	89540	88843	0.778423051	697	PCR BALL CLEAR	RO7T40T21
1	162860	161685	0.721478571	1175	PCR BALL CLEAR	RO7T40T21
1	162268	161936	0.204599798	332	PCR BALL CLEAR	RO7T40T21
1	126221	125719	0.397715119	502	PCR BALL CLEAR	RO7T40T21
1	168844	168125	0.425836867	719	PCR BALL CLEAR	RO7T40T21
1	92069	90492	1.7128458	1577	PCR BALL CLEAR	RO7T40T21
1	130140	127729	1.852620255	2411	PCR BALL CLEAR	RO7T40T21
1	89748	87890	2.07024112	1858	PCR BALL CLEAR	RO7T40T21
1	73653	73348	0.414103974	305	PCR BALL CLEAR	RO7T40T21
1	135962	135031	0.684750151	931	PCR BALL CLEAR	RO7T40T21
1	64852	63966	1.366187627	886	PCR BALL CLEAR	RO7T40T21
1	109573	108329	1.135316182	1244	PCR BALL CLEAR	RO7T40T21
1	126030	124815	0.964056177	1215	PCR BALL CLEAR	RO7T40T21
1	161240	158578	1.650955098	2662	PCR BALL CLEAR	RO7T40T21
1	47025	44060	6.305156831	2965	PCR BALL CLEAR	RO7T40T21
1	48010	45100	6.061237242	2910	PCR BALL CLEAR	RO7T40T21
1	41572	38971	6.256615029	2601	PCR BALL CLEAR	RO7T40T21
1	92520	89065	3.734327713	3455	PCR BALL CLEAR	RO7T40T21
1	35799	33003	7.81027403	2796	PCR BALL CLEAR	RO7T40T21
1	95464	88000	7.818654152	7464	PCR BALL CLEAR	RO7T40T21
1	26372	23924	9.282572425	2448	PCR BALL CLEAR	RO7T40T21
1	105488	93536	11.3301987	11952	PCR BALL CLEAR	RO7T40T21
1	48393	47799	1.227450251	594	PCR BALL CLEAR	RO7T40T21
1	129064	127464	1.239695035	1600	PCR BALL CLEAR	RO7T40T21

Table 2 continued:

SET PT.(T_S)	**PREFORM TEMP.(T_p)**	**% ACCEPTANCE**	**OPERATOR(P_o)**

106	106	91.435225	OPERATOR H
106	107	97.212524	OPERATOR H
106	105.7	99.003008	OPERATOR G
106	106.8	98.995574	OPERATOR G
100	102	98.998545	OPERATOR G
118	117.6	86.889533	OPERATOR I
118	119.3	99.148058	OPERATOR J
110	126.2	99.843771	OPERATOR J
106	105.9	96.920496	OPERATOR J
106	105.8	97.220369	OPERATOR J
106	105.4	95.763365	OPERATOR J
106	106.1	96.039634	OPERATOR J
116	116	95.999535	OPERATOR K
116	116	99.324485	OPERATOR K
112	111	97.572579	OPERATOR K
112	106	98.252923	OPERATOR K
117	117	98.995916	OPERATOR K
117	117	98.812236	OPERATOR K
117	115	99.013581	OPERATOR K
116	116.7	99.221577	OPERATOR J
116	115.8	99.278521	OPERATOR J
112	109	99.7954	OPERATOR J
117	117.4	99.602285	OPERATOR J
117	117.4	99.574163	OPERATOR J
117	117.5	98.287154	OPERATOR J
117	117.2	98.14738	OPERATOR J
117	116.6	97.929759	OPERATOR J
116	116	99.585896	OPERATOR L
116	115	99.31525	OPERATOR L
114	112	98.633812	OPERATOR E
114	112	98.864684	OPERATOR E
110	110	99.035944	OPERATOR E
111	110	98.349045	OPERATOR E
116	120	93.694843	OPERATOR L
116	122	93.938763	OPERATOR L
105	108	93.743385	OPERATOR L
106	107	96.265672	OPERATOR L
101	100	92.189726	OPERATOR G
100	101	92.181346	OPERATOR G
112	110	90.717428	OPERATOR G
112	111	88.669801	OPERATOR G
110	110	98.77255	OPERATOR G
110	110	98.760305	OPERATOR G

Table 3:

LINE	BOTTLES	BOTTLES	%	DEFECTS	RESIN(PCR/VIRGIN)	RESIN

	IN	OUT	DEFECT(Q)			IDENTITY
2	90161	88921	1.375317488	1240	PCR BALL CLEAR	R07T40/T21
2	156754	153621	1.99867308	3133	PCR BALL CLEAR	R07T40/T21
2	75216	73266	2.592533504	1950	PCR BALL CLEAR	R07T40/T21
2	139330	136967	1.695973588	2363	PCR BALL CLEAR	R07T40/T21
2	15614	15520	0.602023825	94	PCR BALL CLEAR	R07T40/T21
2	16461	16395	0.400947695	66	PCR BALL CLEAR	R07T40/T21
2	81613	80613	1.22529499	200	PCR BALL CLEAR	R07T40/T21
2	105629	102245	3.20366566	3384	PCR BALL CLEAR	R07T40/T21
2	76602	74837	2.304117386	1765	PCR BALL CLEAR	R07T40/T21
2	109120	106589	2.319464809	2539	PCR BALL CLEAR	R07T40/T21
2	68151	67470	0.999251662	681	PCR BALL CLEAR	R07T40/T21
2	142926	138925	2.799350713	4001	PCR BALL CLEAR	R07T40/T21
2	96275	95871	0.419631265	404	PCR BALL CLEAR	R07T40/T21
2	178852	177895	0.535079283	957	PCR BALL CLEAR	R07T40/T21
2	93126	91263	2.000515431	1863	PCR BALL CLEAR	R07T40/T21
2	174666	172686	1.133592113	1980	PCR BALL CLEAR	R07T40/T21
2	104674	104472	0.19298011	202	PCR BALL CLEAR	R07T40/T21
2	87951	87071	1.000557128	880	PCR BALL CLEAR	R07T40/T21
2	163398	163396	0.001224005	2	PCR BALL CLEAR	R07T40/T21
2	103927	102556	1.319195204	1371	PCR BALL CLEAR	R07T40/T21
2	193198	190595	1.347322436	2603	PCR BALL CLEAR	R07T40/T21
2	131564	130192	1.042838466	1372	PCR BALL CLEAR	R07T40/T21
2	97882	96125	1.795018492	1757	PCR BALL CLEAR	R07T40/T21
2	163705	159451	2.598576708	4254	PCR BALL CLEAR	R07T40/T21
2	18535	18362	0.933369301	173	PCR BALL CLEAR	R07T40/T21
2	89296	88356	1.052678731	940	PCR BALL CLEAR	R07T40/T21
2	165489	164105	0.836309362	1384	PCR BALL CLEAR	R07T40/T21
2	90046	89001	1.160517957	1045	PCR BALL CLEAR	R07T40/T21
2	176093	175992	0.057356056	101	PCR BALL CLEAR	R07T40/T21
2	99147	97298	1.864907662	1849	PCR BALL CLEAR	R07T40/T21
2	188049	187275	0.41159485	774	PCR BALL CLEAR	R07T40/T21
2	166283	165425	0.515987804	858	PCR BALL CLEAR	R07T40/T21
2	148555	146824	1.165225001	1731	PCR BALL CLEAR	R07T40/T21
2	185924	184716	0.649727846	1208	PCR BALL CLEAR	R07T40/T21
2	121588	120709	0.722933184	879	PCR BALL CLEAR	R07T40/T21
2	194659	193158	0.771092012	1501	PCR BALL CLEAR	R07T40/T21
2	70380	67885	3.545041205	2495	PCR BALL CLEAR	R07T40/T21
2	152828	149572	2.130499647	3256	PCR BALL CLEAR	R07T40/T21
2	7799	7512	3.679958969	287	PCR BALL CLEAR	R07T40/T21
2	31612	29368	7.098570163	2244	PCR BALL CLEAR	R07T40/T21
2	126448	117472	7.098570163	8976	PCR BALL CLEAR	R07T40/T21
2	32038	31976	0.193520195	62	PCR BALL CLEAR	R07T40/T21

Table 3 continued:

SET	PREFORM	%	OPERATOR(Po)

PT.(Ts)	TEMP.(Tp)	ACCEPTANCE	
115	116	98.624683	OPERATOR B
115	115	98.001327	OPERATOR B
118	120	97.407466	OPERATOR N
118	116	98.304026	OPERATOR N
106	104.8	99.397976	OPERATOR C
106	105.5	99.599052	OPERATOR C
102	101	98.774705	OPERATOR D
125	123.4	96.796334	OPERATOR A
125	115.2	97.695883	OPERATOR A
118	114.7	97.680535	OPERATOR A
117	114	99.000748	OPERATOR B
117	114	97.200649	OPERATOR B
117	114	99.580369	OPERATOR B
117	115	99.464921	OPERATOR B
118	115	97.999485	OPERATOR B
118	115	98.866408	OPERATOR B
112	111	99.80702	OPERATOR B
117	117	98.999443	OPERATOR B
117	118	99.998776	OPERATOR B
117	118	98.680805	OPERATOR B
117	117	98.652678	OPERATOR B
114	114	98.957162	OPERATOR B
115	111.1	98.204982	OPERATOR A
117	116.1	97.401423	OPERATOR A
117	115	99.066631	OPERATOR A
118	118.2	98.947321	OPERATOR A
116	116.2	99.163691	OPERATOR A
115	115.1	98.839482	OPERATOR A
112	112.1	99.942644	OPERATOR A
115	113.9	98.135092	OPERATOR A
114	114.1	99.588405	OPERATOR A
117	114.6	99.484012	OPERATOR A
117	117	98.834775	OPERATOR A
117	117.5	99.350272	OPERATOR A
117	116.7	99.277067	OPERATOR A
117	117	99.228908	OPERATOR A
117	115	96.454959	OPERATOR E
111	111	97.8695	OPERATOR D
110	110	96.320041	OPERATOR C
115	112	92.90143	OPERATOR C
117	110	92.90143	OPERATOR C
111	110	99.80648	OPERATOR C

Table 4:

LINE	BOTTLES	BOTTLES	DEFECTS	%DEFECT(Q)	RESIN(PCR/VIRGIN)	RESIN

	IN	OUT				IDENTITY
2	137105	136538	567	0.413551657	BALLPCR CLEAR	R22T42/R19T21
2	173941	172283	1658	0.953196774	BALLPCR CLEAR	R22T42/R19T21
2	117659	117285	374	0.317867736	BALLPCR CLEAR	R22T42/R19T21
2	184528	183720	808	0.437873927	BALLPCR CLEAR	R22T42/R19T21
2	138180	136570	1610	1.16514691	BALLPCR CLEAR	R22T42/R19T21
2	196650	195018	1632	0.829900839	BALLPCR CLEAR	R22T42/R19T21
2	107477	106660	817	0.760162639	BALLPCR CLEAR	R22T42/R19T21
2	28347	25660	687	9.478957209	BALLPCR CLEAR	R22T42/R19T21
2	148797	145585	3212	2.158645672	BALLPCR CLEAR	R22T42/R19T21
2	16117	15956	161	0.998945213	BALLPCR CLEAR	R22T42/R19T21

Table 4 continued:

SET PT.(Ts)	PREFORM TEMP.(Tp)	%ACCEPTANCE	OPERATOR(Po)
118.1	118.6	99.586448	OPERATOR A
122	122.1	99.046803	OPERATOR A
122	114.4	99.682132	OPERATOR A
122	115	99.562126	OPERATOR A
120	121.2	98.834853	OPERATOR A
120	119.6	99.170099	OPERATOR A
118	119	99.239837	OPERATOR B
122	122	90.521043	OPERATOR B
122	113	97.841354	OPERATOR B
106	110.5	99.001055	OPERATOR C

Table 5:

LINE	BOTTLES IN	BOTTLES OUT	% DEFECT(Q)	DEFECTS	RESIN(PCR/VIRGIN)	RESIN IDENTITY
1	73791	73057	0.994701251	734	VIRGIN CLEAR	NOVOPAK
1	131750	130566	0.898671727	1184	VIRGIN CLEAR	NOVOPAK
1	190845	190500	0.180774974	345	VIRGIN CLEAR	NOVOPAK
1	72992	66764	8.532441911	6228	VIRGIN CLEAR	NOVOPAK
1	122364	111372	8.983034226	10992	VIRGIN CLEAR	NOVOPAK
1	61119	54717	10.47464782	6402	VIRGIN CLEAR	NOVOPAK
1	93773	92780	1.058940207	993	VIRGIN CLEAR	NOVOPAK
1	95629	94639	1.035250813	990	VIRGIN CLEAR	NOVOPAK
1	176727	174431	1.29917896	2296	VIRGIN CLEAR	NOVOPAK
1	92576	90995	1.707786035	1581	VIRGIN CLEAR	NOVOPAK
1	173281	172563	0.414355873	718	VIRGIN CLEAR	NOVOPAK
1	93699	91067	2.80899476	2632	VIRGIN CLEAR	NOVOPAK
1	158937	157587	0.849393156	1350	VIRGIN CLEAR	NOVOPAK
1	96207	94538	1.734801002	1669	VIRGIN CLEAR	NOVOPAK
1	41572	38971	6.256615029	2601	VIRGIN CLEAR	NOVOPAK
1	92520	89065	3.734327713	3455	VIRGIN CLEAR	NOVOPAK
1	104302	103036	1.213783053	1266	VIRGIN CLEAR	NOVOPAK
1	187142	185649	0.797789914	1493	VIRGIN CLEAR	NOVOPAK
1	97329	96356	0.999702042	973	VIRGIN CLEAR	NOVOPAK
1	191704	191668	0.018778951	36	VIRGIN CLEAR	NOVOPAK
1	101150	100843	0.303509639	307	VIRGIN CLEAR	NOVOPAK
1	158239	157872	0.231927654	367	VIRGIN CLEAR	NOVOPAK
1	51641	50067	3.047965764	1574	VIRGIN CLEAR	NOVOPAK
1	100801	96846	3.923572187	3955	VIRGIN CLEAR	NOVOPAK

Table 5 continued:

SET PT.(Ts)	PREFORM TEMP.(Tp)	% ACCEPTANCE	OPERATOR(Po)
100	101	99.0052987	OPERATOR E
100	100	99.1013283	OPERATOR E
100	100	99.819225	OPERATOR F
100	105.6	91.4675581	OPERATOR A
100	100.5	91.0169658	OPERATOR J
100	101	89.5253522	OPERATOR N
100	102	98.9410598	OPERATOR N
102.5	102.2	98.9647492	OPERATOR N
102.5	102.1	98.700821	OPERATOR N
103	102.8	98.292214	OPERATOR N
100	103.1	99.5856441	OPERATOR N
104	103.1	97.1910052	OPERATOR N
102	102.2	99.1506068	OPERATOR N
104	103.4	98.265199	OPERATOR N
105	108	93.743385	OPERATOR L
106	107	96.2656723	OPERATOR L
103	103	98.7862169	OPERATOR K
103	103	99.2022101	OPERATOR K
103	103	99.000298	OPERATOR K
103	103	99.981221	OPERATOR K
103	102	99.6964904	OPERATOR K
103	102	99.7680723	OPERATOR K
110	110	96.9520342	OPERATOR K
110	110	96.0764278	OPERATOR K

Table 6:

LINE	BOTTLES IN	BOTTLES OUT	% DEFECTS(Q)	DEFECTS	RESIN(PCR/VIRGIN)	RESIN IDENTITY
2	125381	123948	1.142916391	1433	VRGN. NVPK CLEAR	NVPKRO7T40
2	178498	176995	0.842026241	1503	VRGN. NVPK CLEAR	NVPKRO7T40
2	179690	178072	0.900439646	1618	VRGN. NVPK CLEAR	NVPKRO7T40
2	122512	121557	0.779515476	955	VRGN. NVPK CLEAR	NVPKRO7T40
2	110900	108930	1.776375113	1970	VRGN. NVPK CLEAR	NVPKRO7T40
2	156404	155170	0.788982379	1234	VRGN. NVPK CLEAR	NVPKRO7T40
2	41572	38971	6.256615029	2601	VRGN. NVPK CLEAR	NVPKRO7T40

Table 6 continued:

SET PT.(Ts)	PREFORM TEMP.(Tp)	% ACCEPTANCE	OPERATOR(Po)
108	108.1	98.8570836	OPERATOR A
108	108.3	99.1579738	OPERATOR A
104	104	99.0995604	OPERATOR B
108	106.3	99.2204845	OPERATOR A
100	102	98.2236249	OPERATOR D
100	99	99.2110176	OPERATOR D
105	108	93.743385	OPERATOR L

Table 7:

LINE	BOTTLES IN	BOTTLES OUT	% DEFECT(Q)	DEFECTS	RESIN(PCR/VIRGIN)	RESIN IDENTITY
2	13000	12870	1	130	VIRG. NVPK GREEN	R22T42
2	70605	69981	0.8837901	624	VIRG. NVPK GREEN	R22T42
2	98015	96669	1.373259195	1346	VIRG. NVPK GREEN	R22T42
2	94443	93230	1.284372585	1213	VIRG. NVPK GREEN	R22T42
2	96340	93067	3.397342744	3273	VIRG. NVPK GREEN	R22T42
2	57598	53425	7.245043231	4173	VIRG. NVPK GREEN	R22T42
2	117182	112923	3.634517247	4259	VIRG. NVPK GREEN	R22T42
2	78980	78955	0.031653583	25	VIRG. NVPK GREEN	R22T42

Table 7 continued:

SET PT.(Ts)	PREFORM TEMP.(Tp)	% ACCEPTANCE	OPERATOR(Po)
106	111.2	99	OPERATOR C
100	91	99.1162099	OPERATOR D
100	91	98.6267408	OPERATOR D
115	109.6	98.7156274	OPERATOR A
100	101	96.6026573	OPERATOR E
100	99	92.7549568	OPERATOR D
100	102	96.3654828	OPERATOR D
100	100	99.9683464	OPERATOR F

Table 8:

LINE	BOTTLES IN	BOTTLES OUT	% DEFECT(Q)	DEFECTS	RESIN(PCR/VIRGIN)	RESIN IDENTITY
2	54593	52584	3.679958969	2009	NVPK VRGN CLEAR	R2242
2	132712	128152	3.436011815	4560	NVPK VRGN CLEAR	R2242
2	42252	32262	23.64385118	9990	NVPK VRGN CLEAR	R2242
2	112672	111320	1.199943198	1352	NVPK VRGN CLEAR	R2242

Table 8 continued:

SET PT.(Ts)	PREFORM TEMP.(Tp)	% ACCEPTANCE	OPERATOR(Po)
115	110	96.320041	OPERATOR C
100	99	96.563988	OPERATOR C
100	100	76.356149	OPERATOR C
105	105	98.800057	OPERATOR C

Table 9:

LINE	BOTTLES IN	BOTTLES OUT	% DEFECT(Q)	DEFECTS	RESIN(PCR/VIRGIN)	RESIN IDENTITY
1	13000	8100	37.69230769	4900	VIRG. NVPK BLUE	NOVOPAK
1	13000	9750	25	3250	VIRG. NVPK BLUE	NOVOPAK
1	27320	26795	1.921669107	525	VIRG. NVPK BLUE	NOVOPAK
1	98410	98180	0.233716086	230	VIRG. NVPK BLUE	NOVOPAK

Table 9 continued:

SET PT.(Ts)	PREFORM TEMP.(Tp)	% ACCEPTANCE	OPERATOR(Po)
100	102	62.3076923	OPERATOR G
100	103.1	75	OPERATOR G
100	101	98.0783309	OPERATOR F
100	100	99.7662839	OPERATOR F

Comments: Data obtained here is from the research performed at AB Company Corporation, Marion, Illinois. APPENDIX A contains information pertaining to the process operators and on the production line it was performed, the amount of preforms fed to the machine and the amount of resulting bottles after undergoing, all the blow molding processes. The set point, preform temperatures for each unique resin type, was also recorded for all the runs. The percentage acceptance is also calculated, where manufacturing operation with minimal defects is obtained.

APPENDIX B

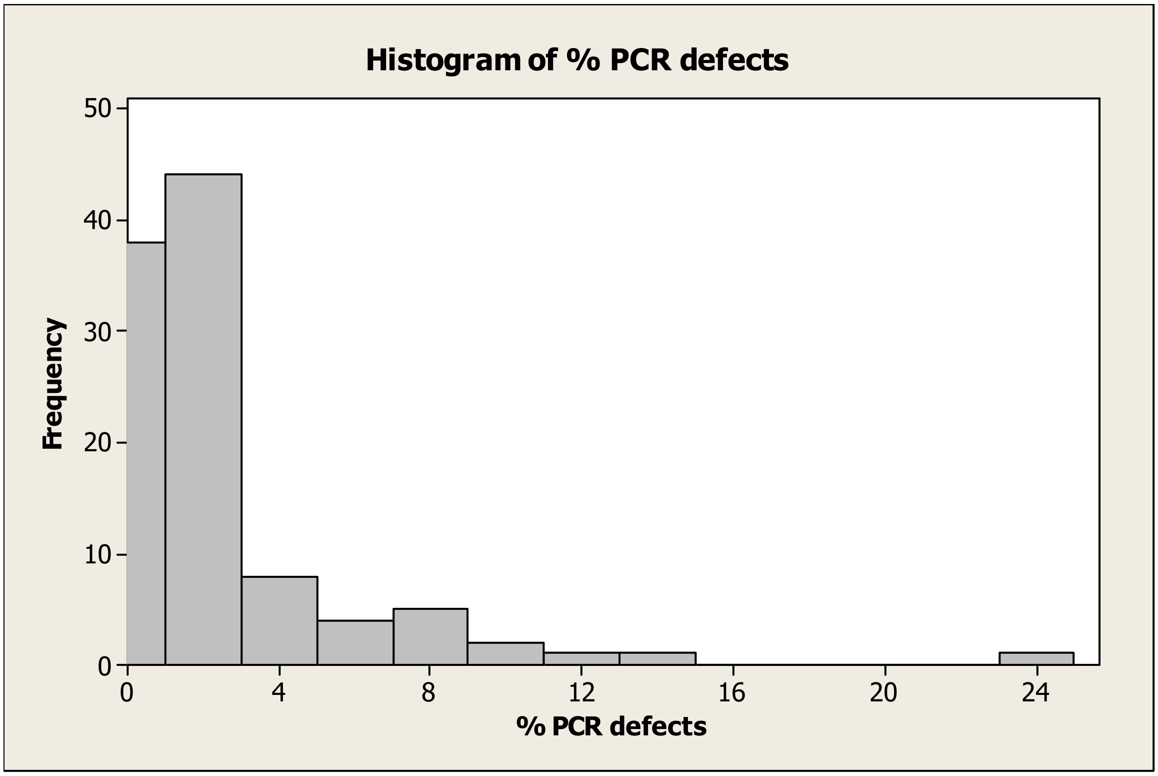


Fig. 1b Histogram of % PCR defects to verify normality

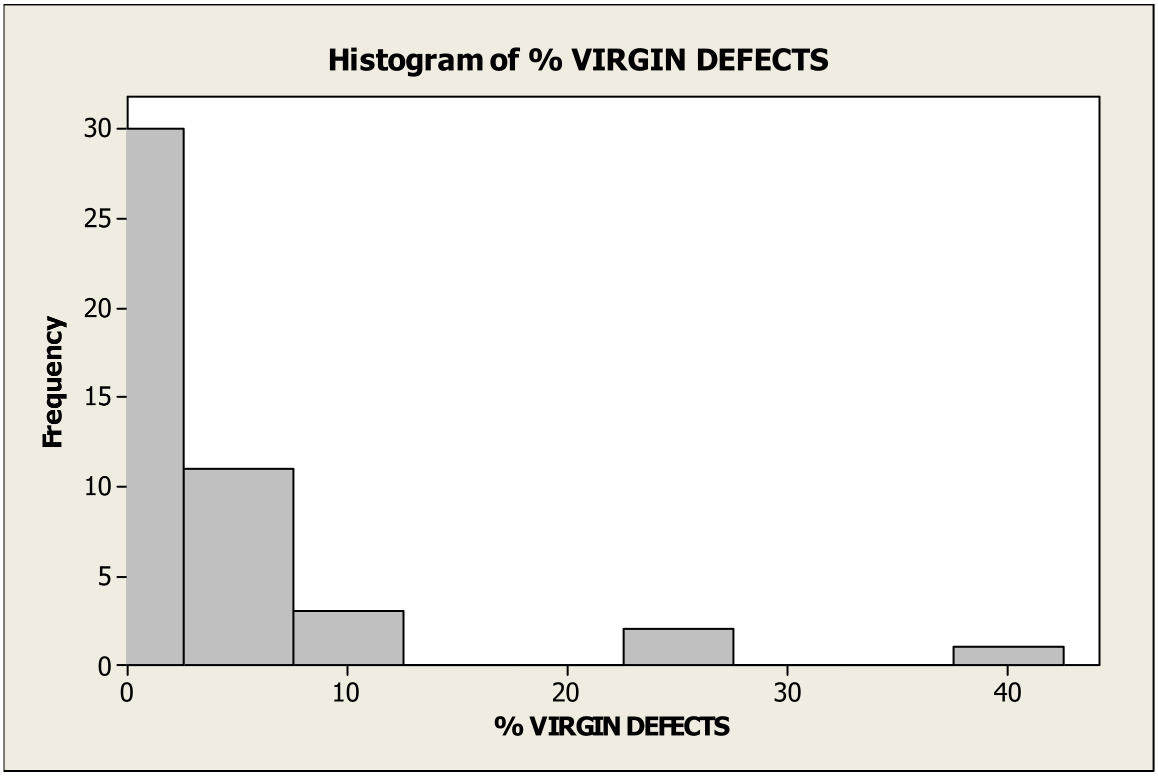


Fig.2b Histogram of % Virgin defects to verify normality

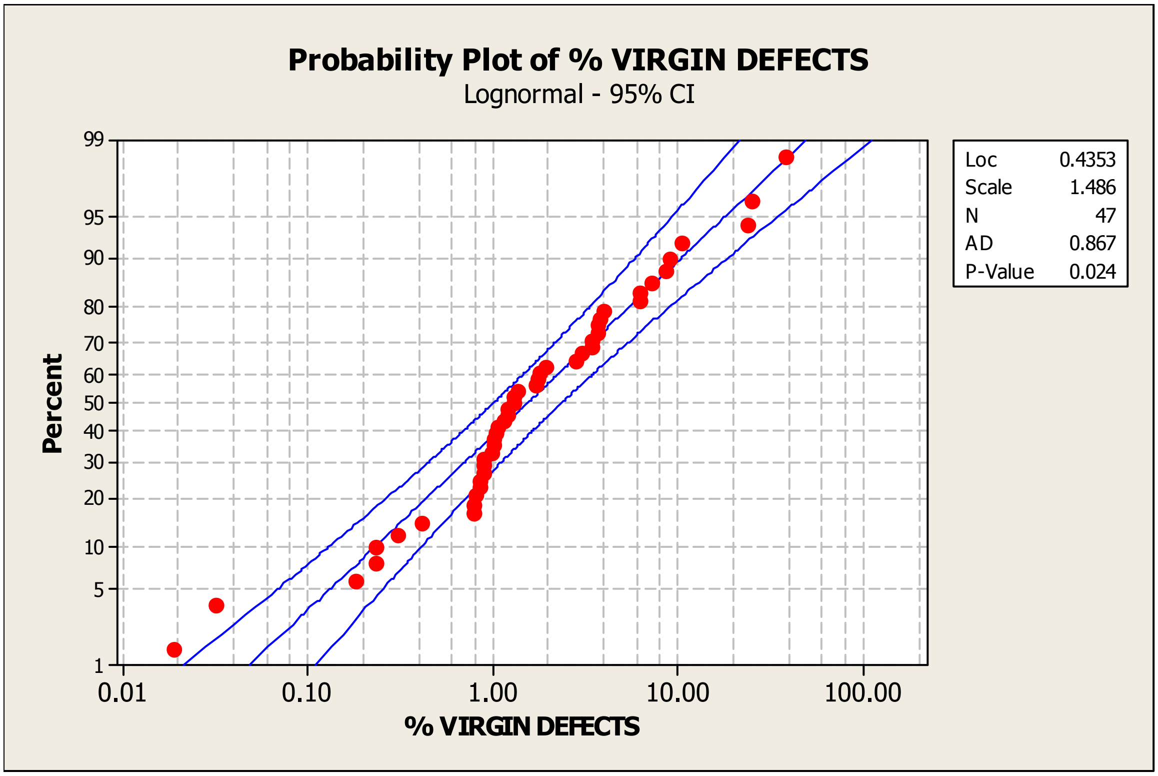


Fig 3b.Probability Plot of % Virgin defects

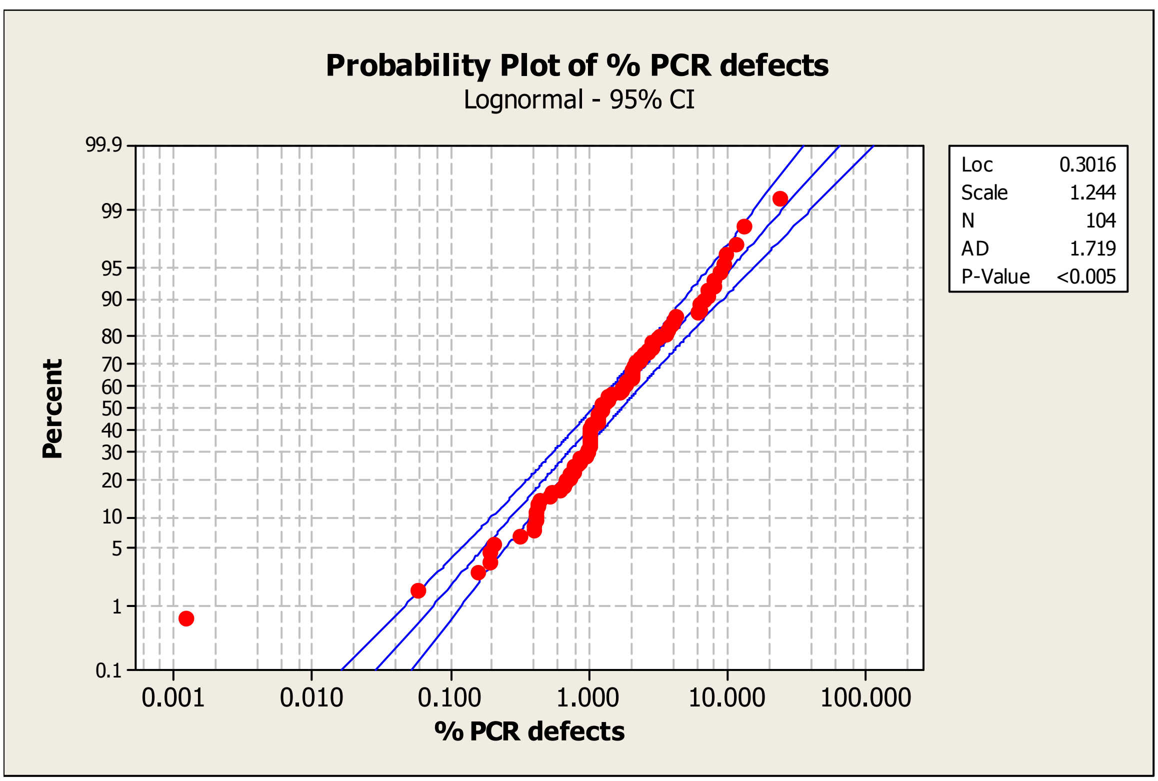


Fig. 4b Probability Plot of % PCR defects

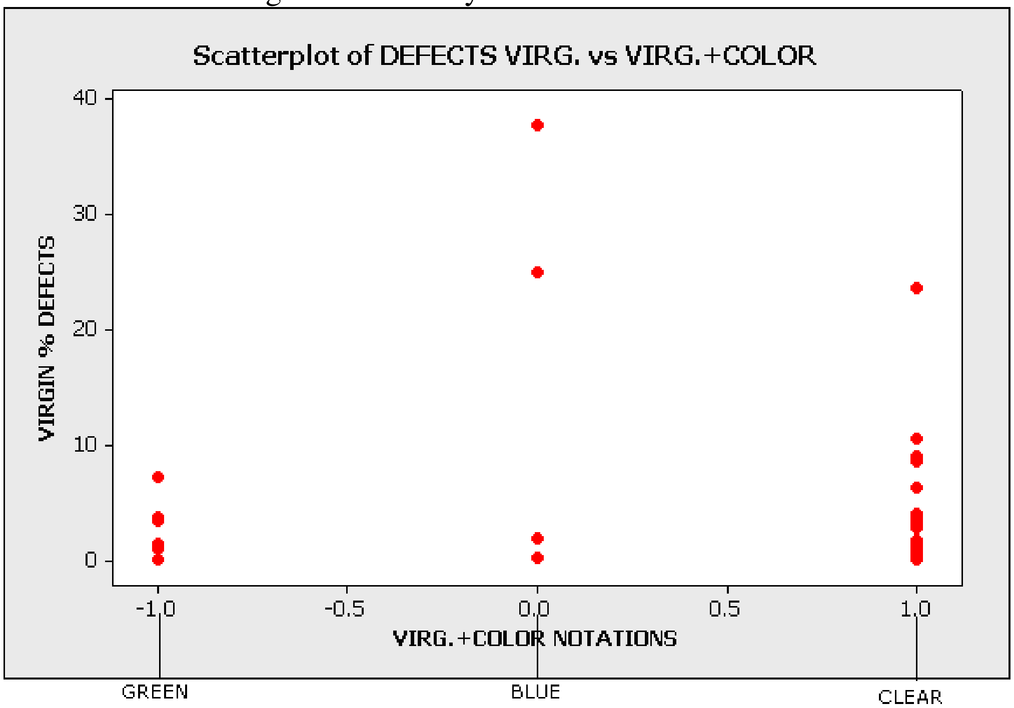


Fig. 5b Scatter plot of % Virgin defects vs. Virgin colors

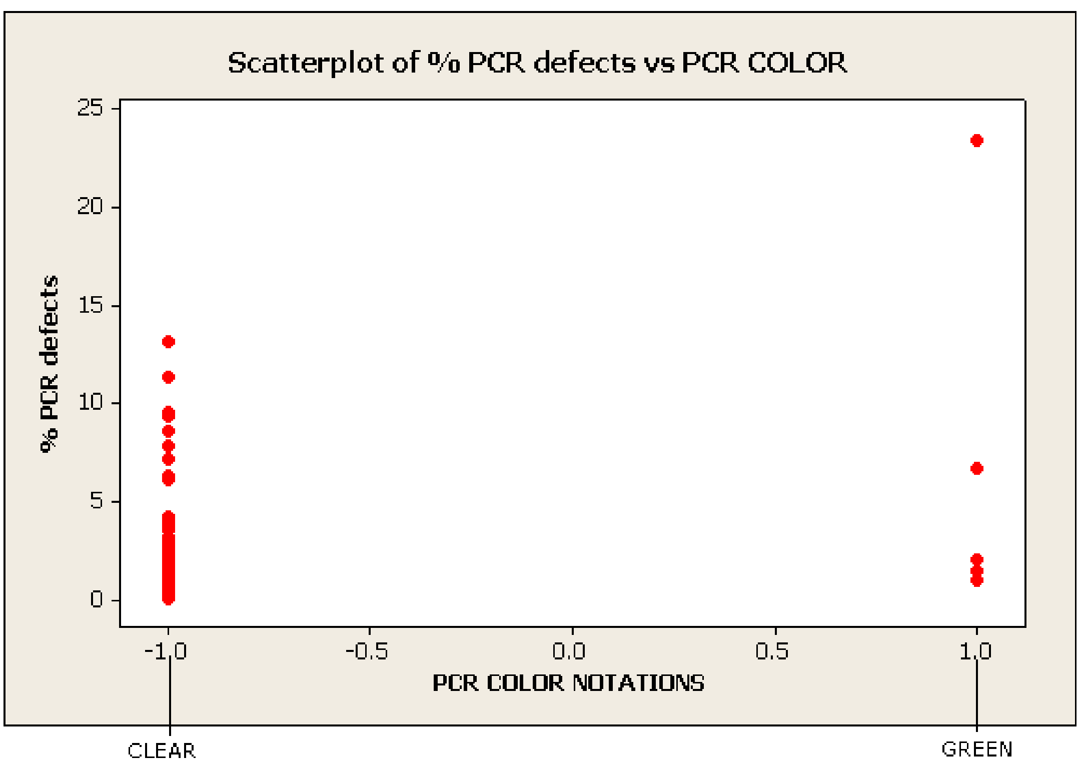


Fig. 6b Scatter plot of % PCR defects vs. PCR colors

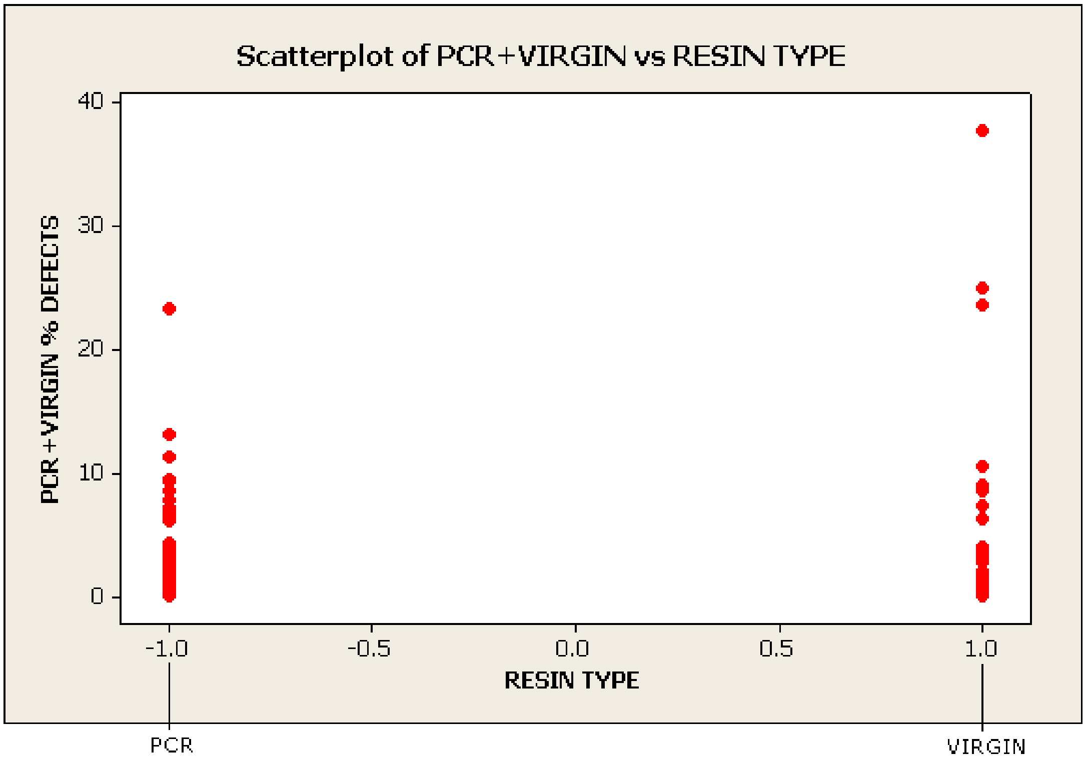


Fig. 7b Scatter plot of PCR+VIRGIN (% DEFECTS) vs. RESIN TYPE

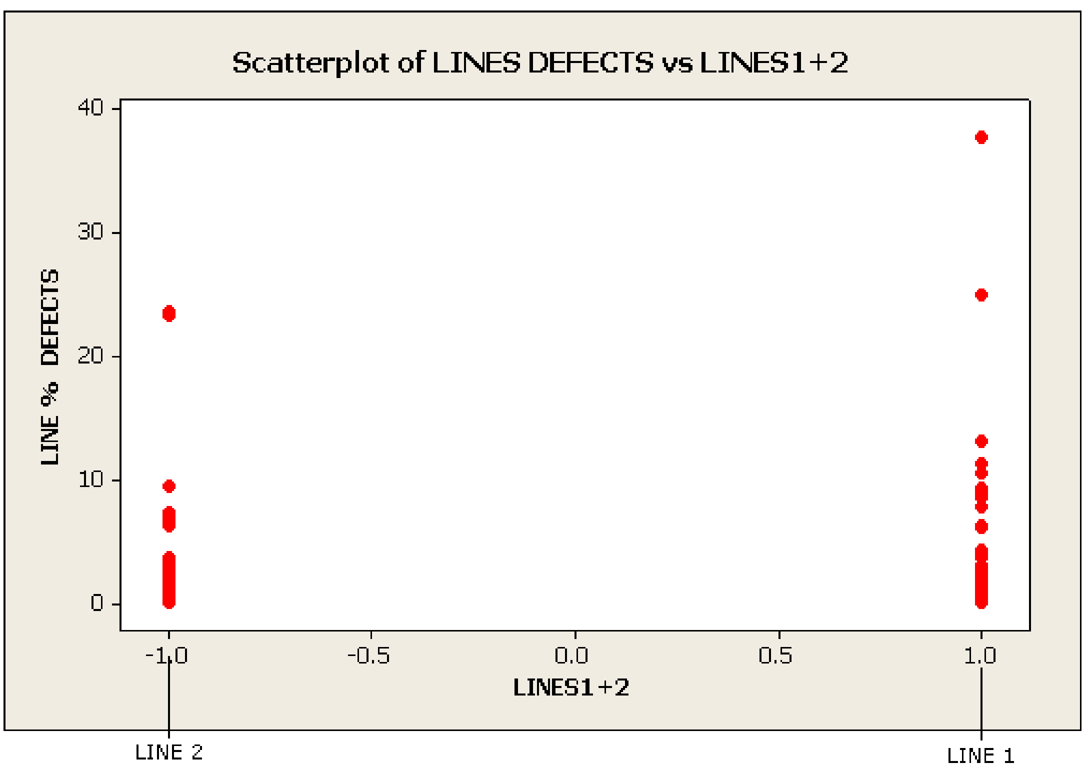
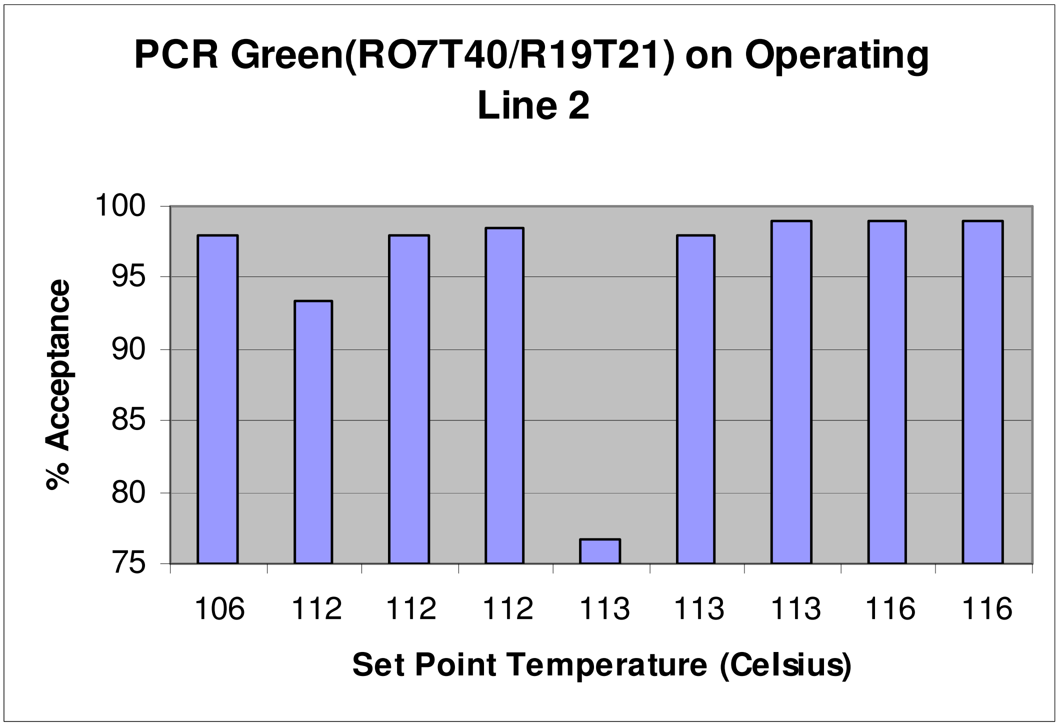


Fig. 8b Scatter plot of operating Line 1 vs. Line 2



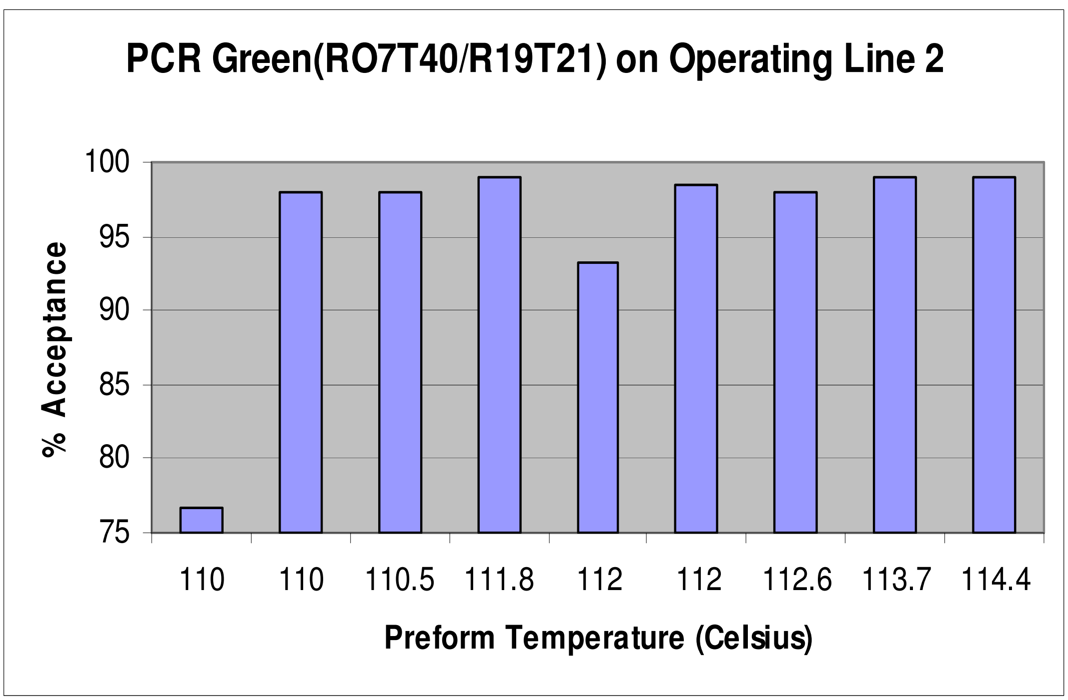
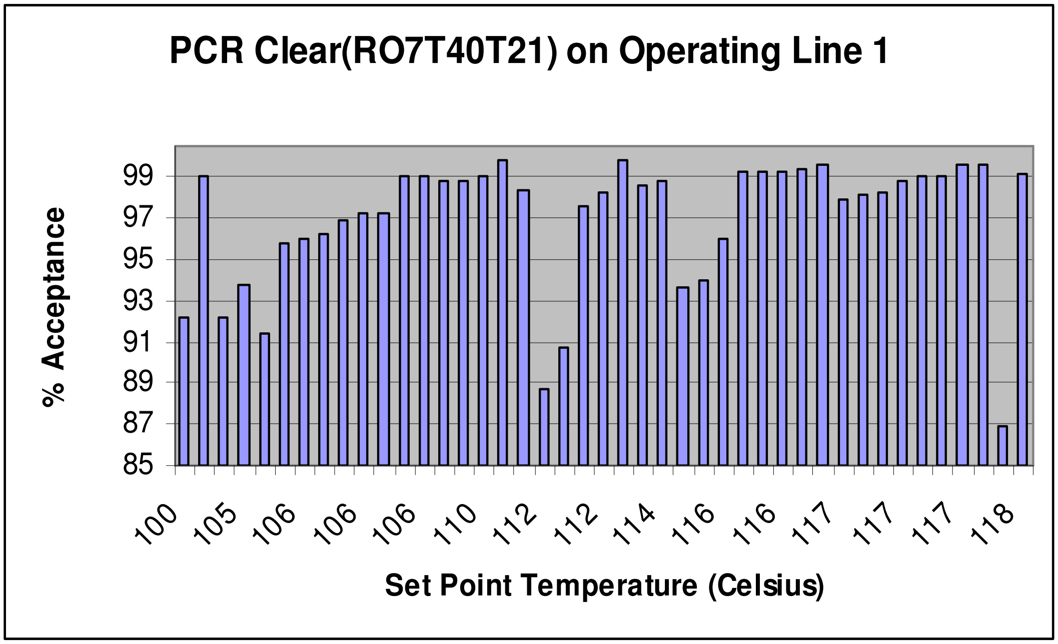


Fig. 9b Acceptance charts for PCR green (RO7T40/R19T21) on operating line 2 for set point and preform temperatures



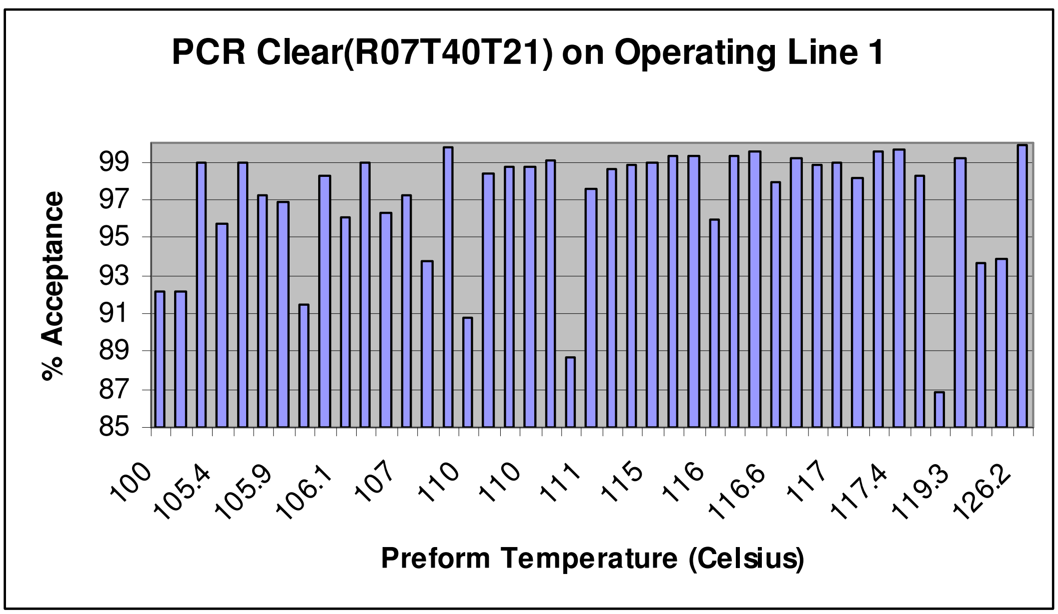
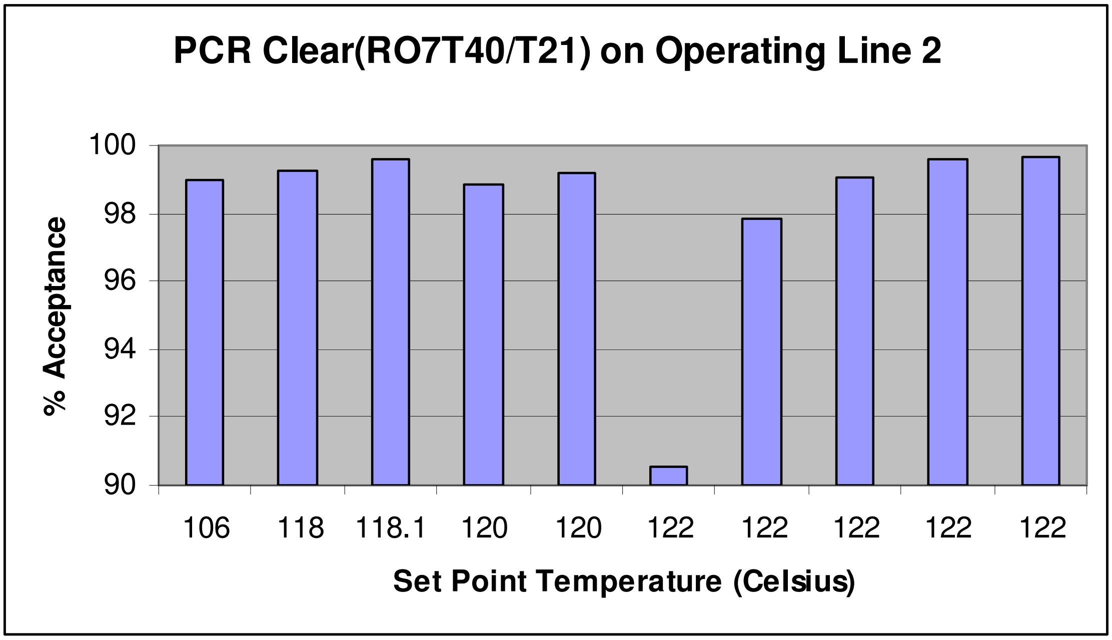


Fig. 10b Acceptance charts for PCR clear (RO7T40T21) on operating line 1 for set point and preform temperatures


PCR Clear(RO7T40/T21) on Operating Line 2
% Acceptance
100
98
96
94
92
90
106 118 118.1 120 120 122 122 122 122 122
Set Point Temperature (Celsius)

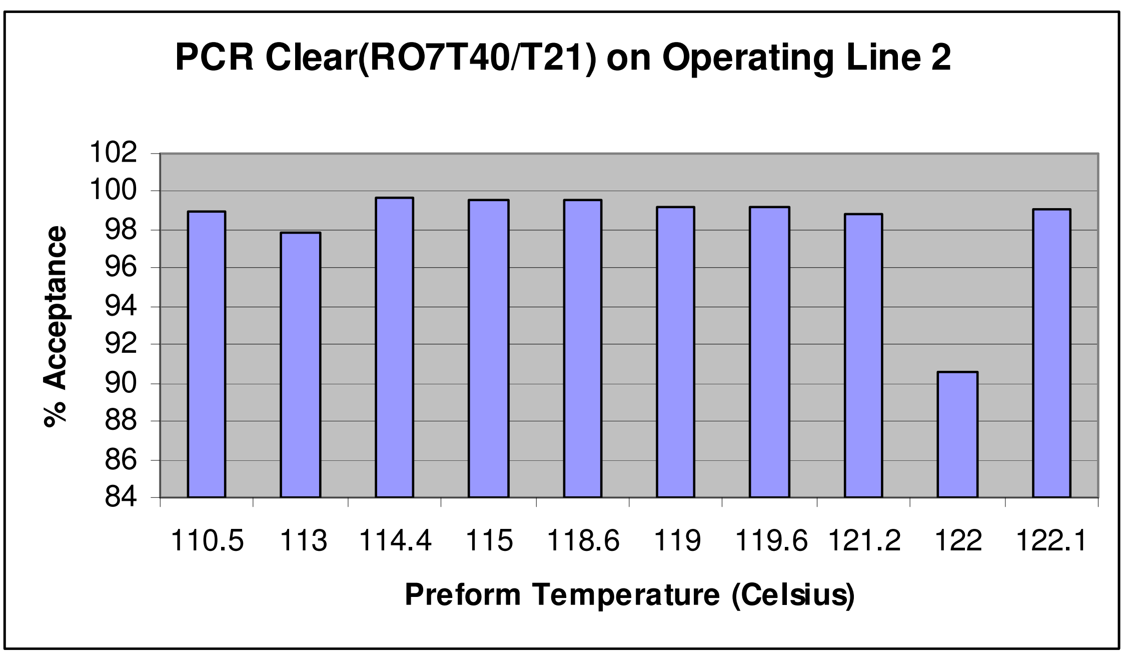

PCR Clear(RO7T40/T21) on Operating Line 2
% Acceptance
102
100
98
96
94
92
90
88
86
84
110.5 113 114.4 115 118.6 119 119.6 121.2 122 122.1
Preform Temperature (Celsius)

Fig. 11b Acceptance charts for PCR clear (R07T40/T21) on operating line 2 for set point and preform temperatures

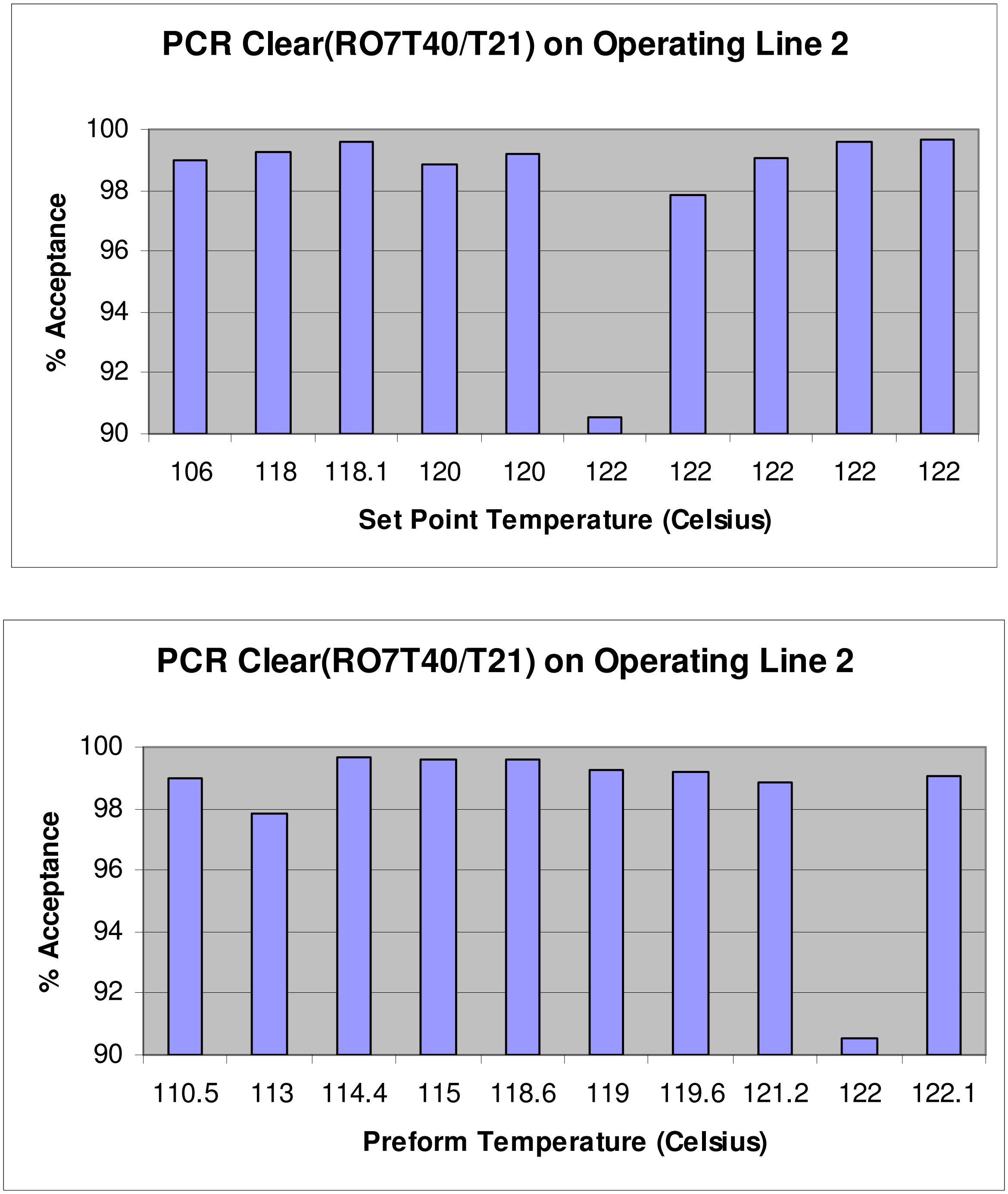
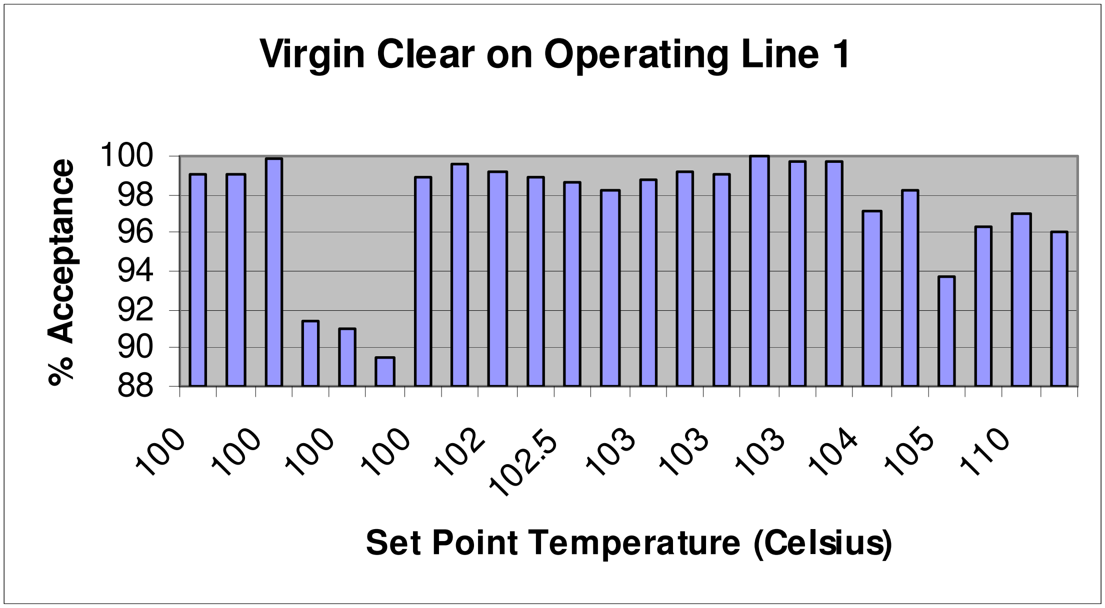


Fig .12b Acceptance charts for PCR clear (R22T42/R19T21) on operating line 2 for set point and preform temperatures



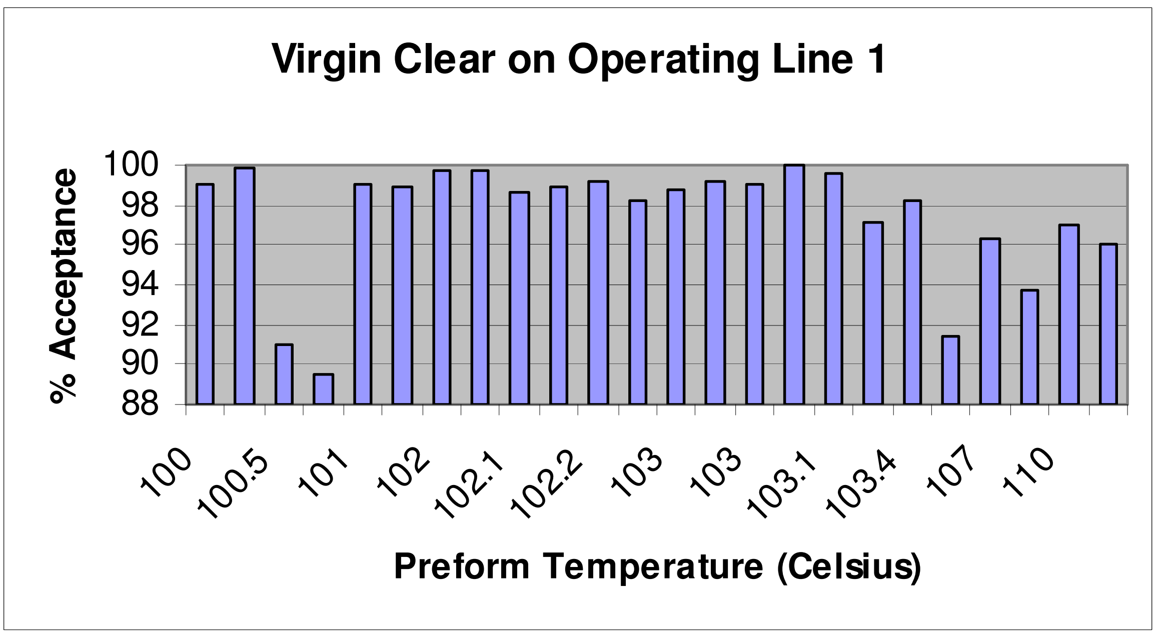
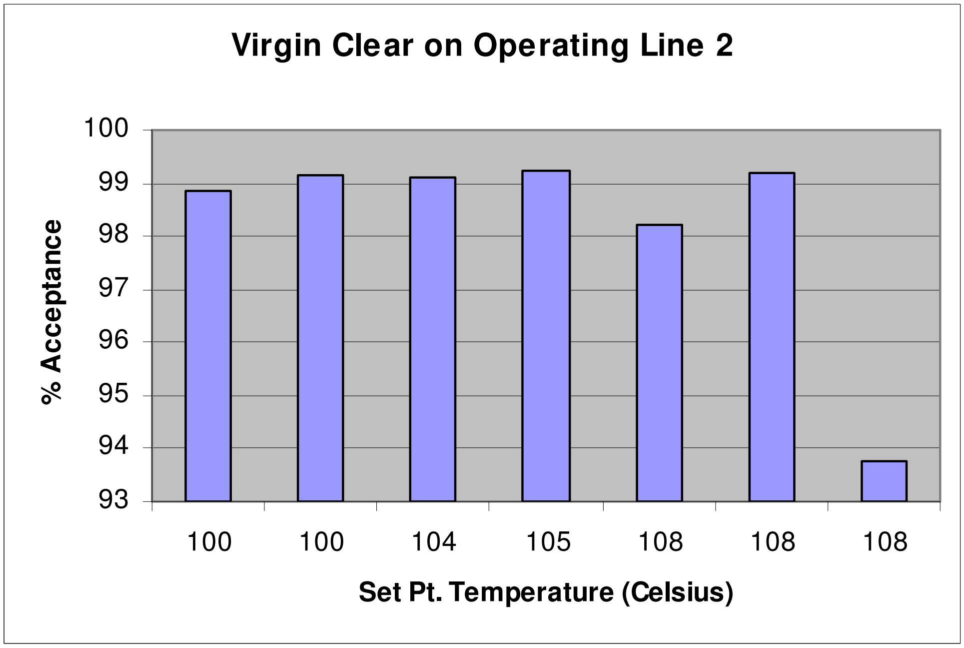


Fig. 13b Acceptance charts for Virgin clear on operating line 1 for set point and preform temperatures



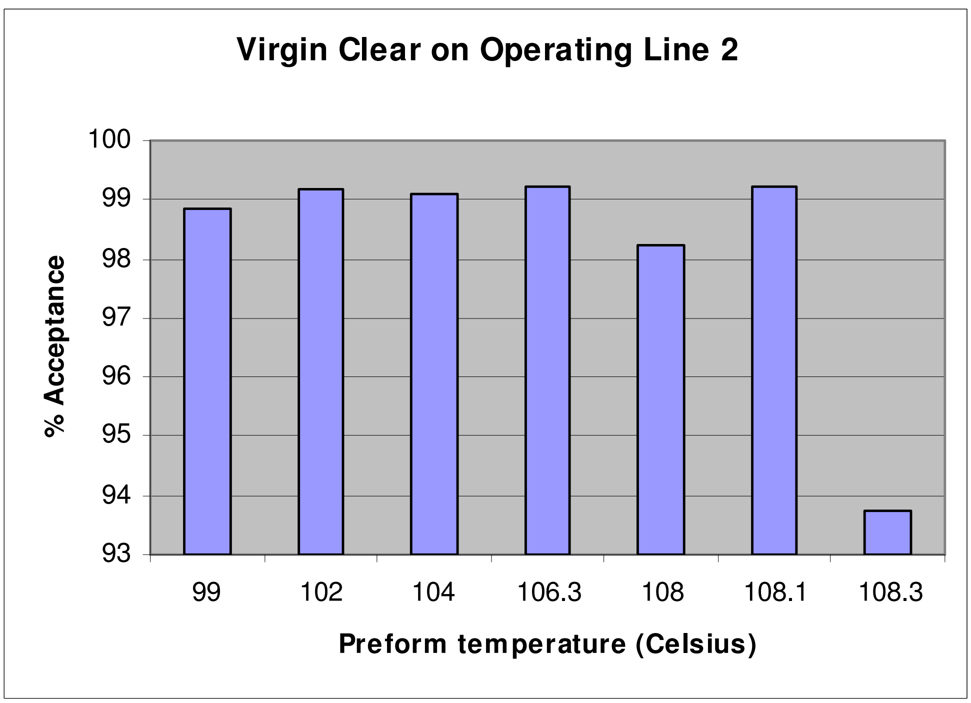
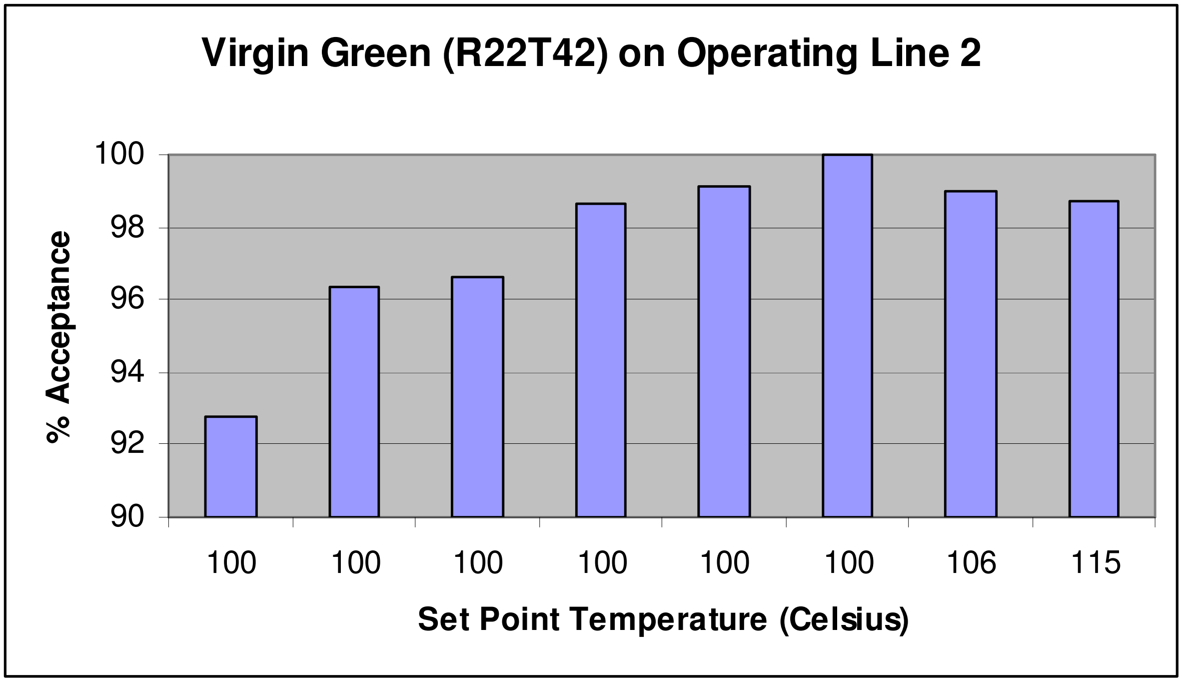


Fig. 14b Acceptance charts for Virgin clear (RO7T40) on operating line 2 for set point and preform temperatures



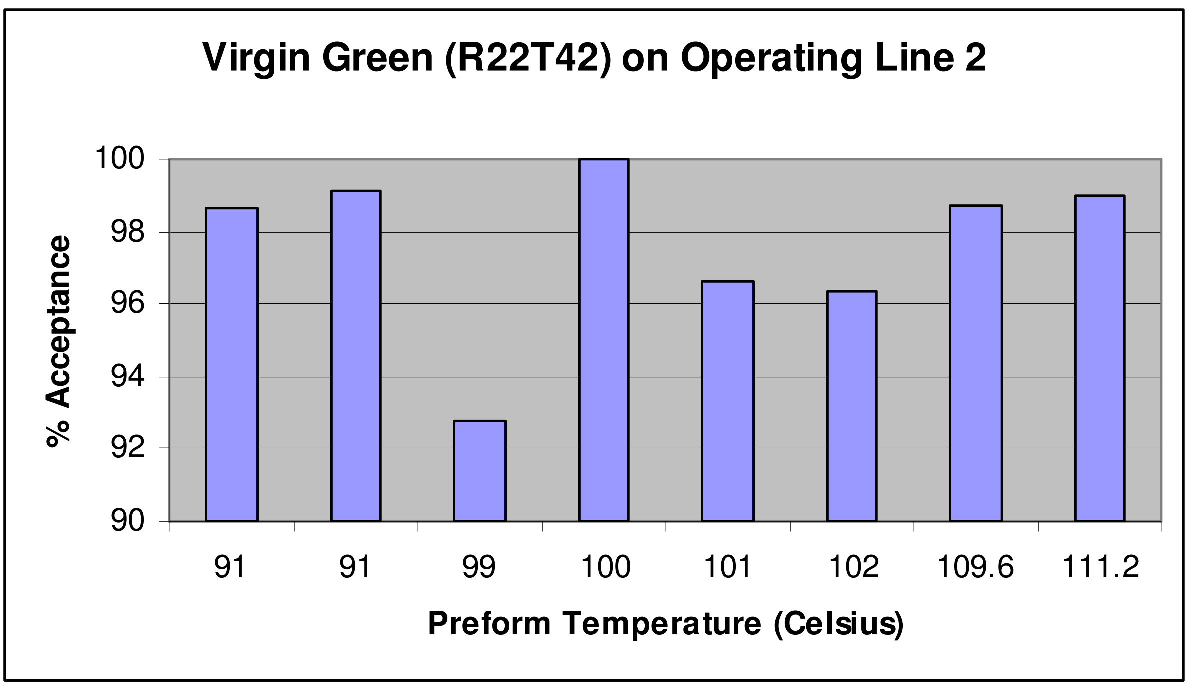
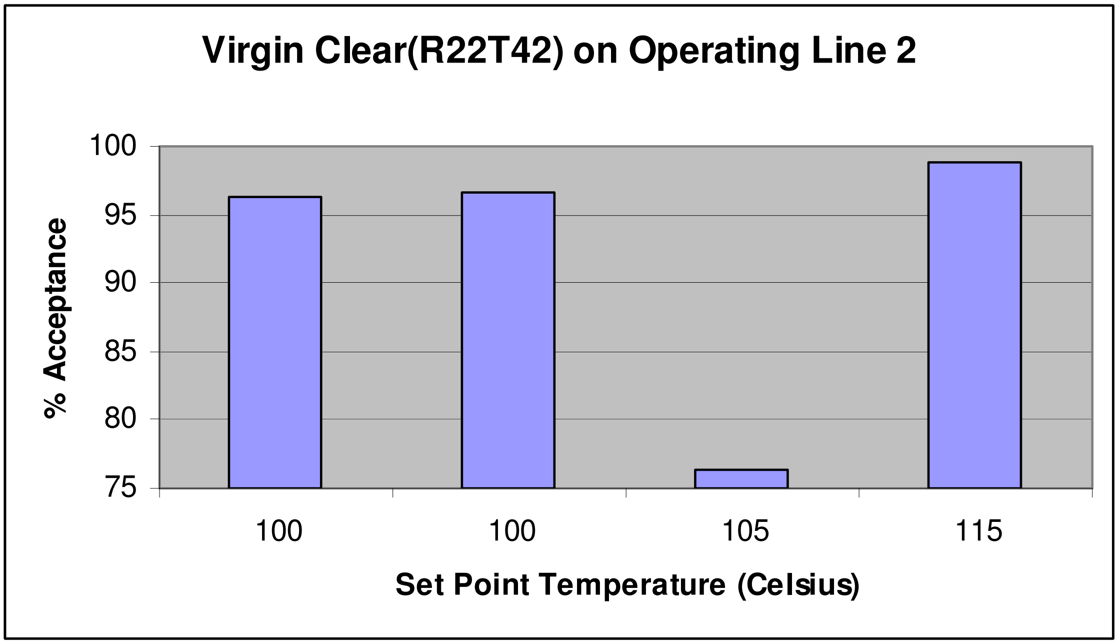


Fig. 15b Acceptance charts for Virgin green (R22T42) on operating line 2 for set point and preform temperatures


Virgin Clear(R22T42) on Operating Line 2
100
95
90
85
80
75
% Acceptance
100
100
105
115
Set Point Temperature (Celsius)

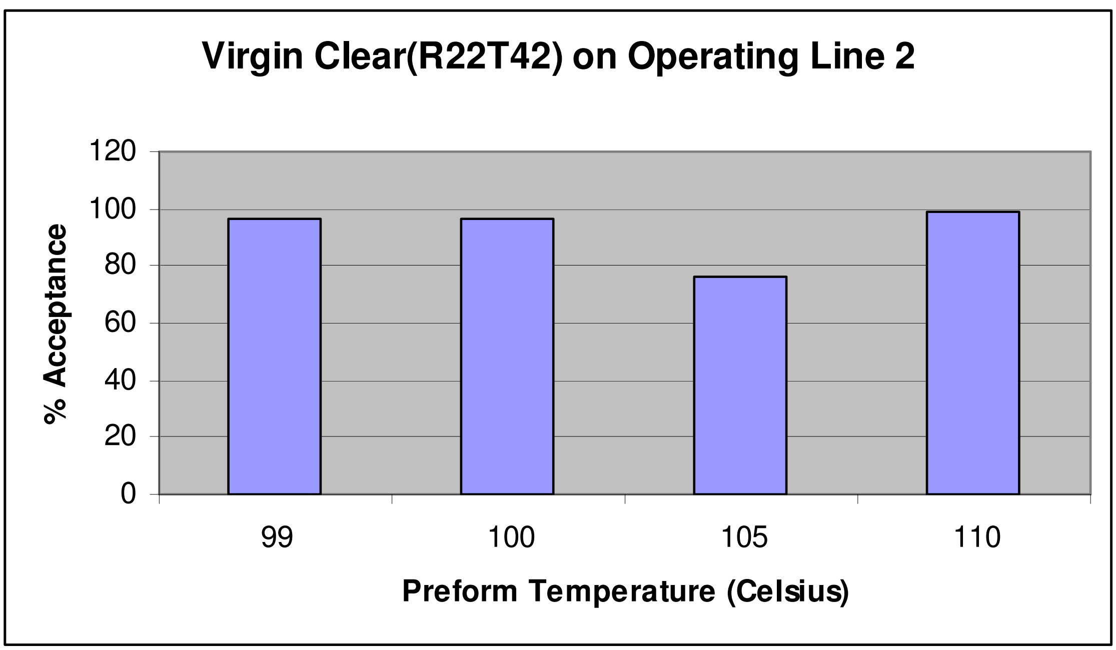
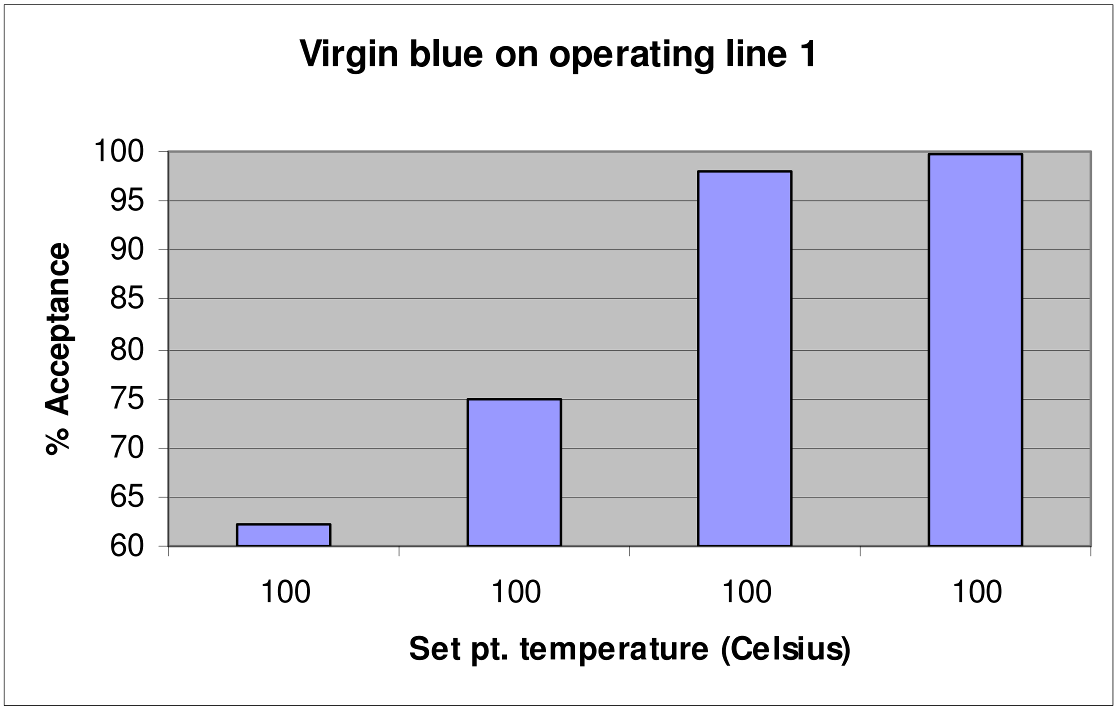

Virgin Clear(R22T42) on Operating Line 2
120
100
80
60
40
20
0
% Acceptance
99
100
105
110
Preform Temperature (Celsius)

Fig. 16b Acceptance charts for Virgin clear (R2242) on operating line 2 for set point and preform temperatures



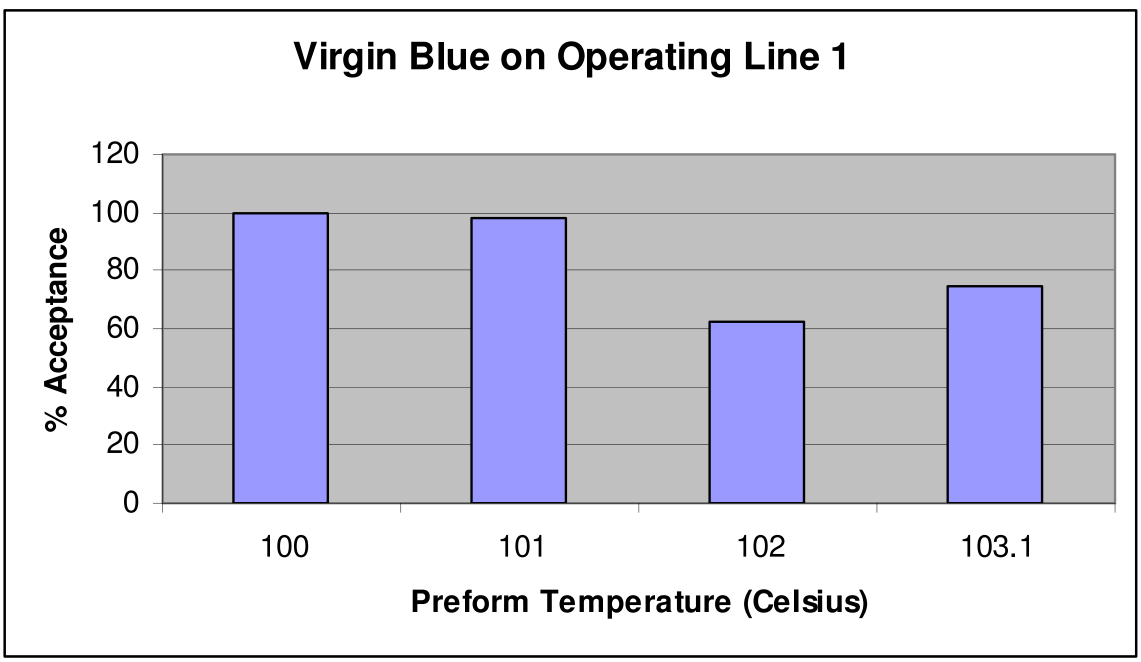


Fig. 17b Acceptance charts for Virgin blue on operating line 1 for set point and preform temperatures

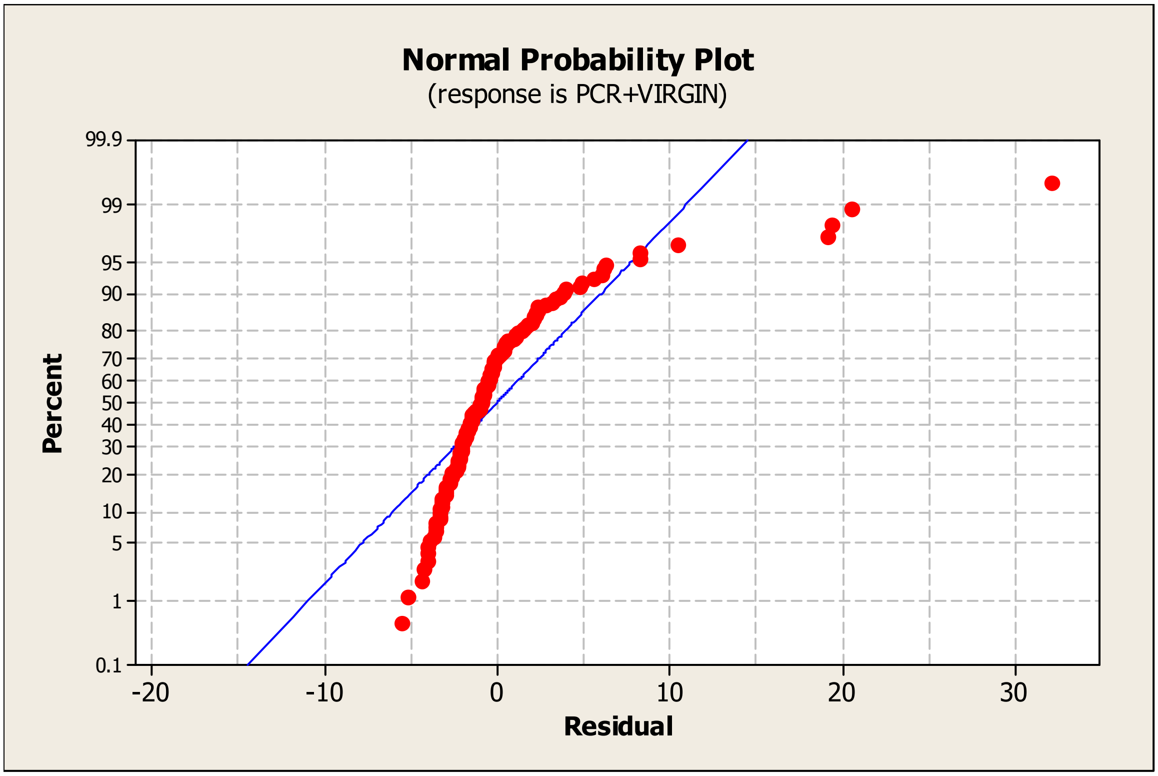


Fig. 18b Normal probability plot response for PCR & Virgin % defects (Residuals)

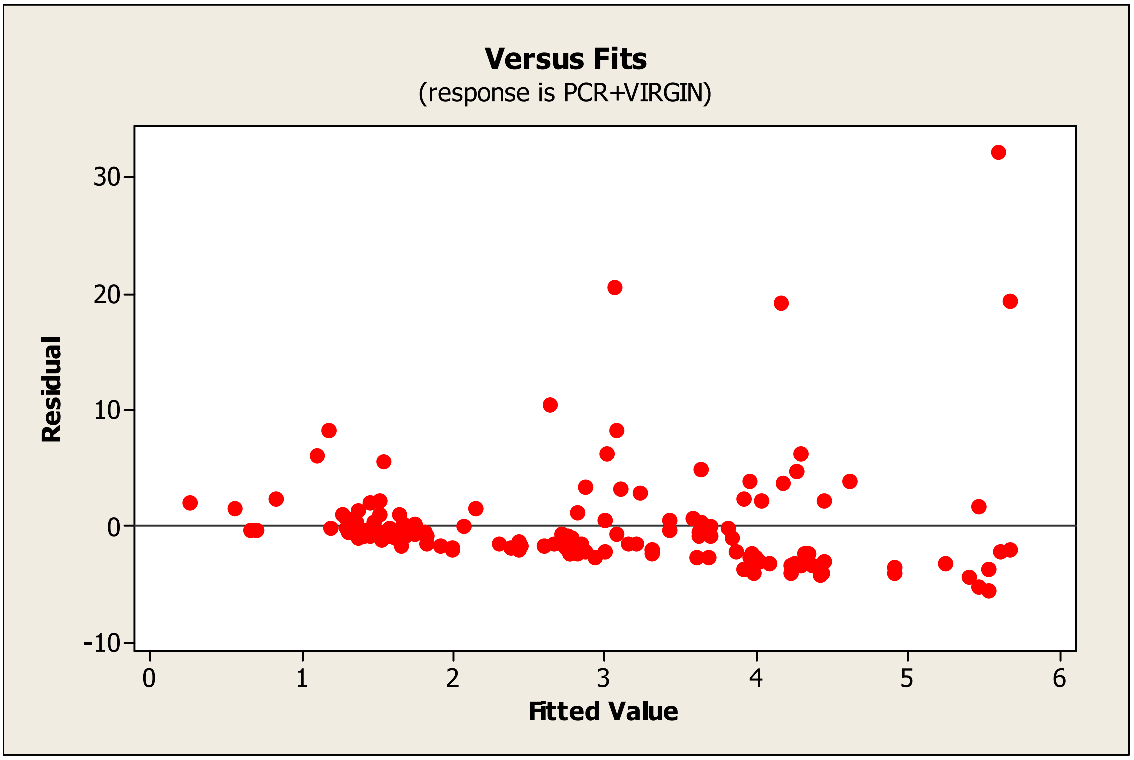


Fig. 19b Versus Fits for PCR & Virgin % defects (Residuals)

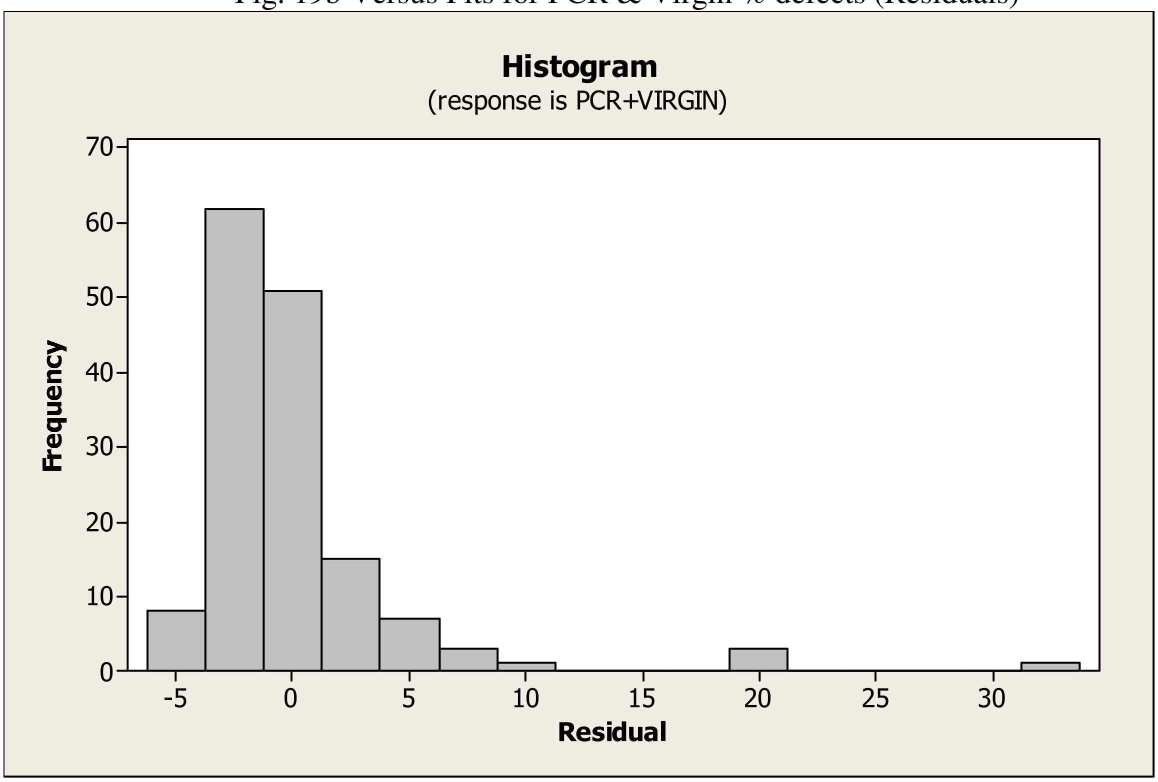


Fig. 20b Histogram for PCR &Virgin defects (residual)

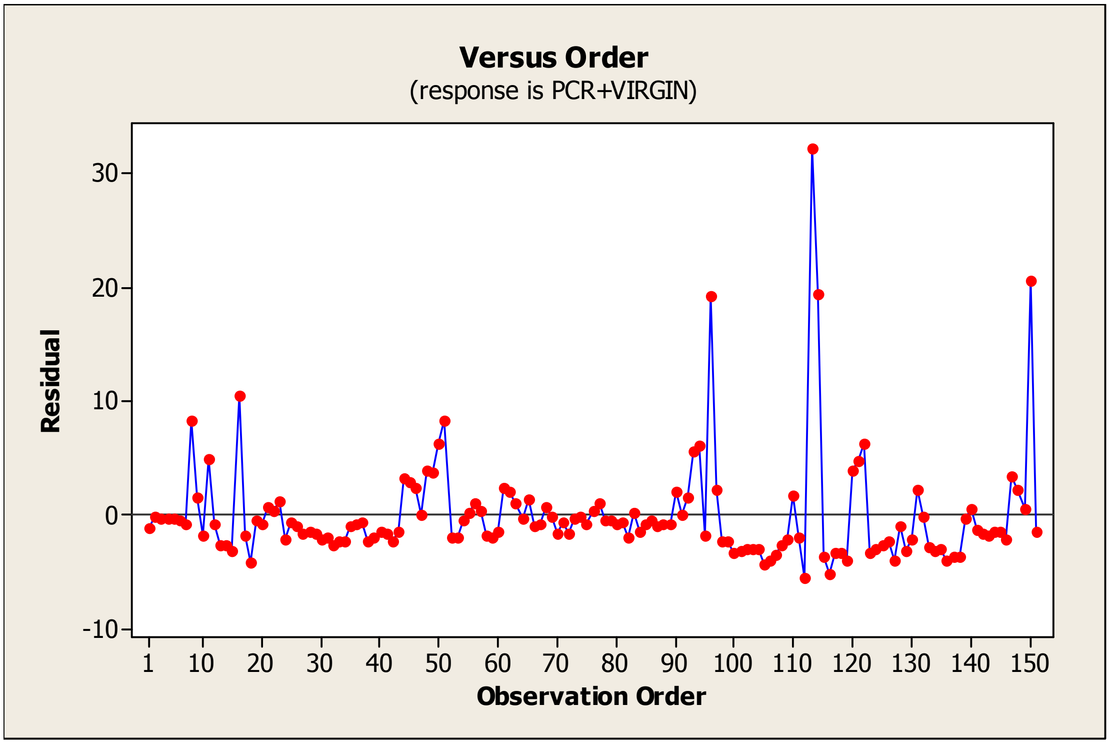


Fig. 21b Versus order plot for PCR+Virgin % defects (Residuals)

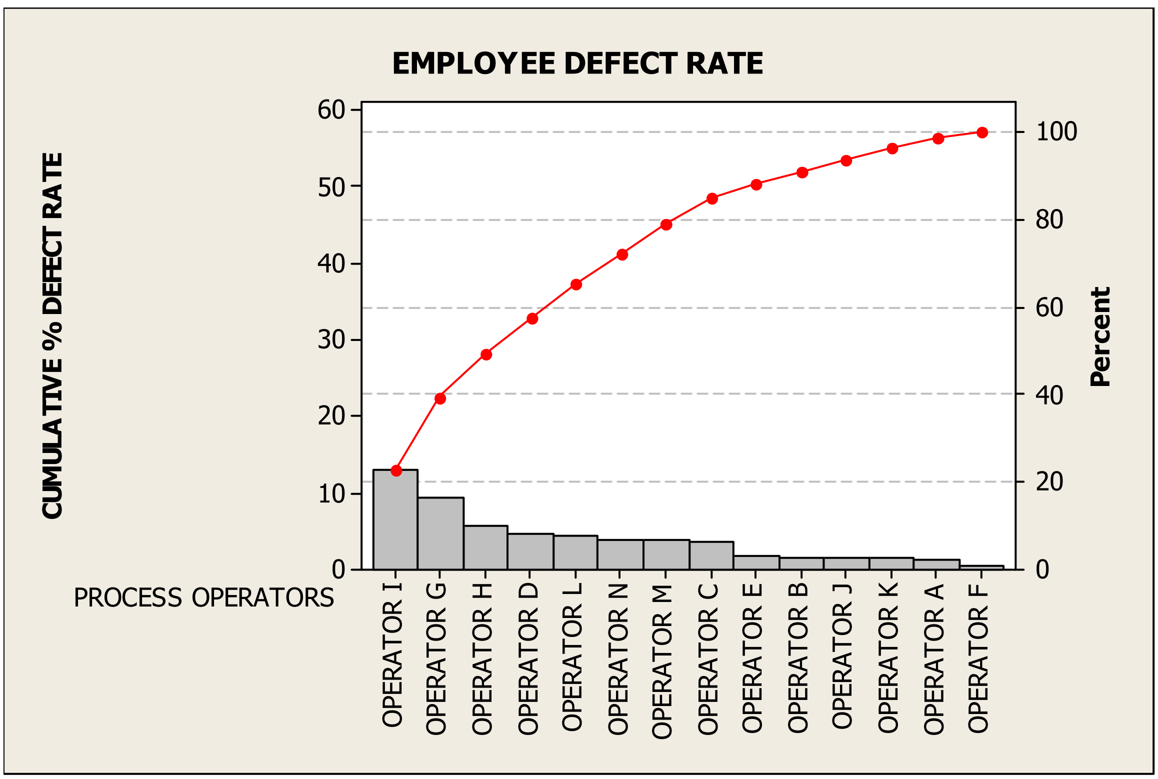


Fig.22b. Employee % defect Pareto Chart

Comments: In APPENDIX B, the key independent variables are plotted into scatter plots which are used for correlation analysis and the probability plots are use to test for normality. The setpoint and the preform temperatures were plotted against an accepted level for minimal defects. The residual plots were retrieved through the regression analysis, when conducted through MINITAB™ statistical software. Also, the employee defect rate is depicted through a Pareto chart.

APPENDIX C

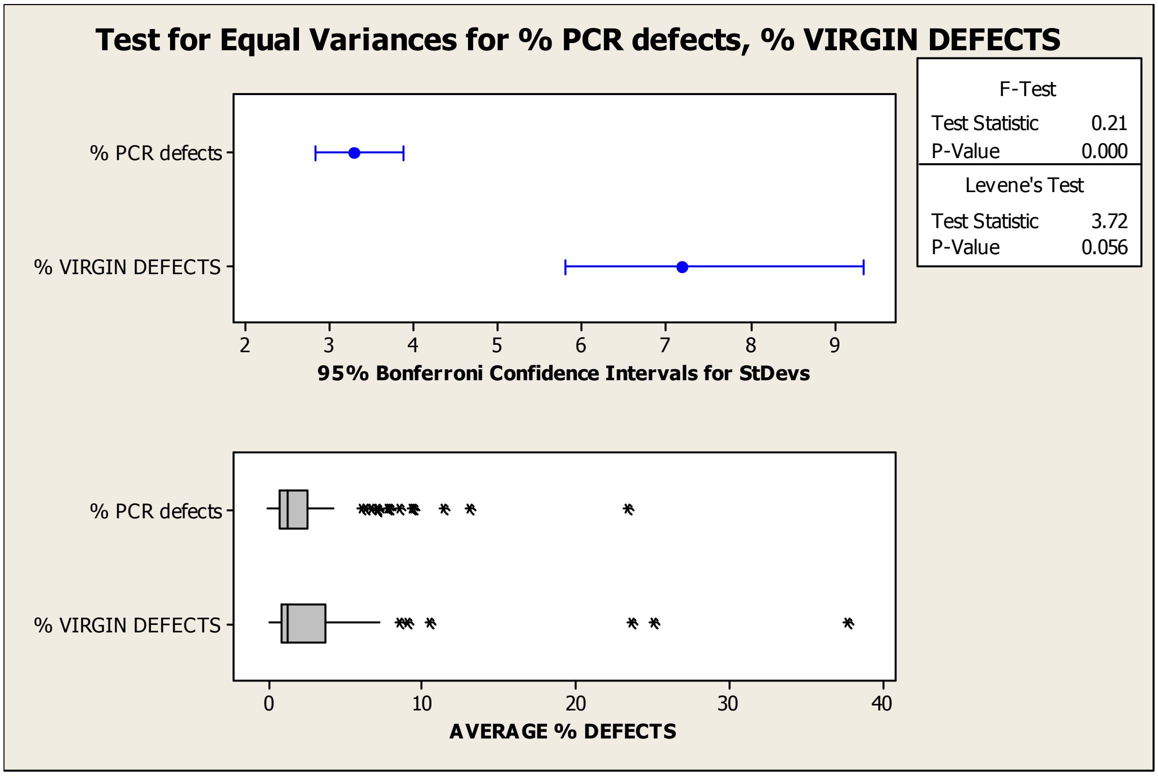


Fig. 1c Test for Equal Variances for % PCR Defects vs. % Virgin Defects

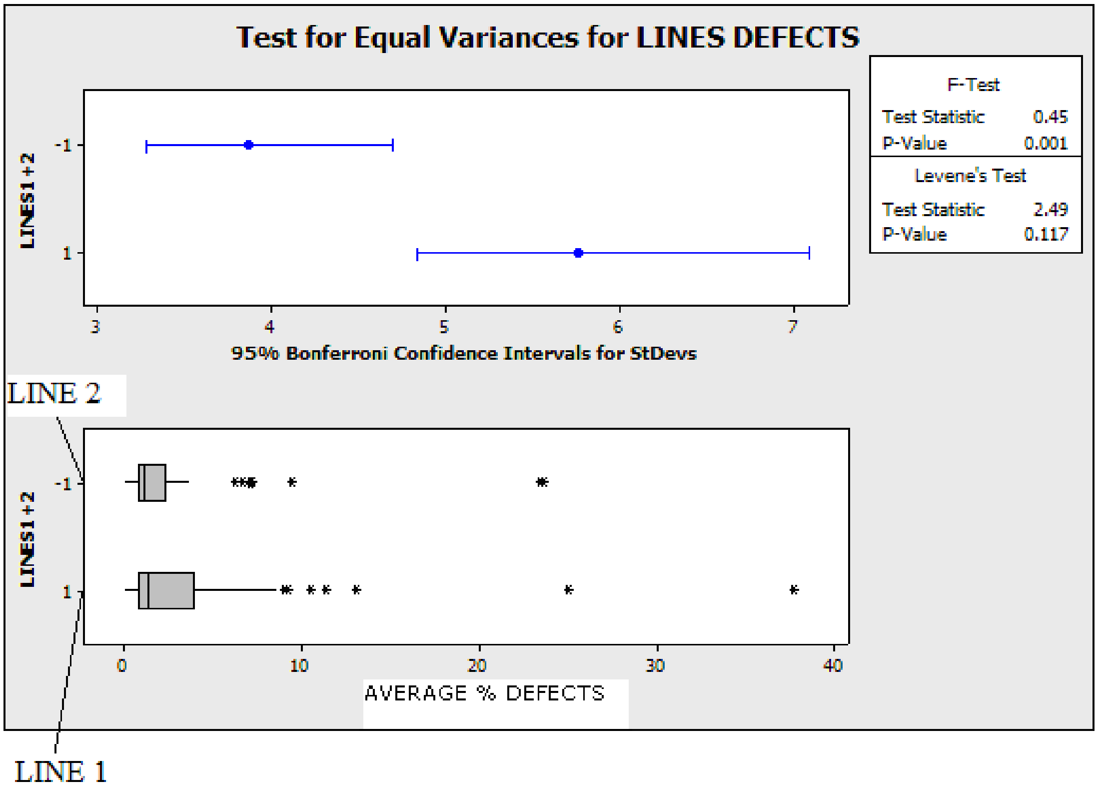


Fig. 2c Test for Equal Variances for Operating Line 1 vs. Line 2

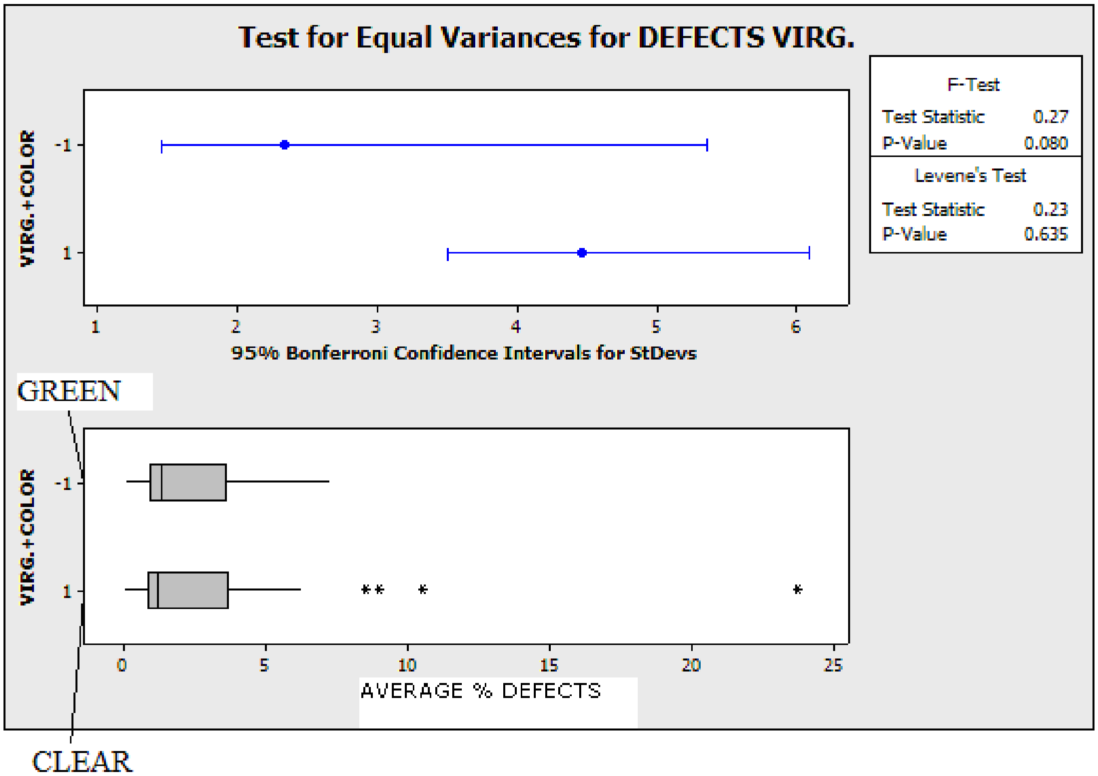


Fig. 3c Test for Equal Variances for Virgin Green vs. Virgin Clear

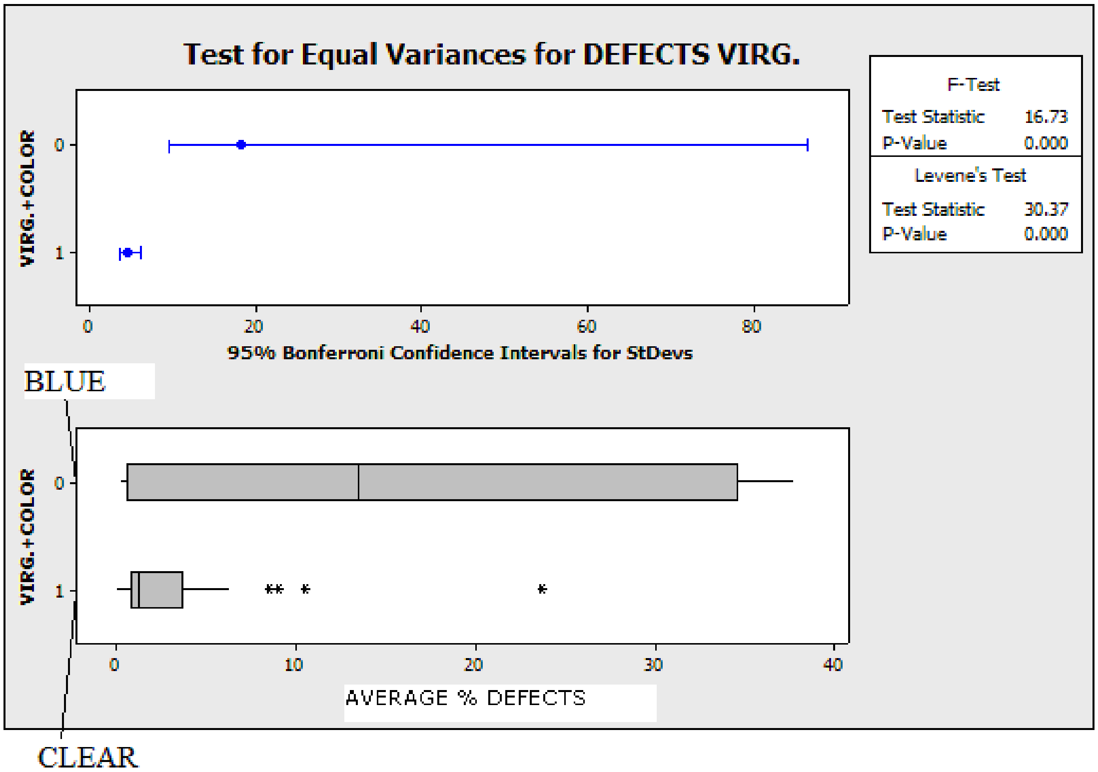


Fig. 4c Test for Equal Variances for Virgin Blue vs. Virgin Clear

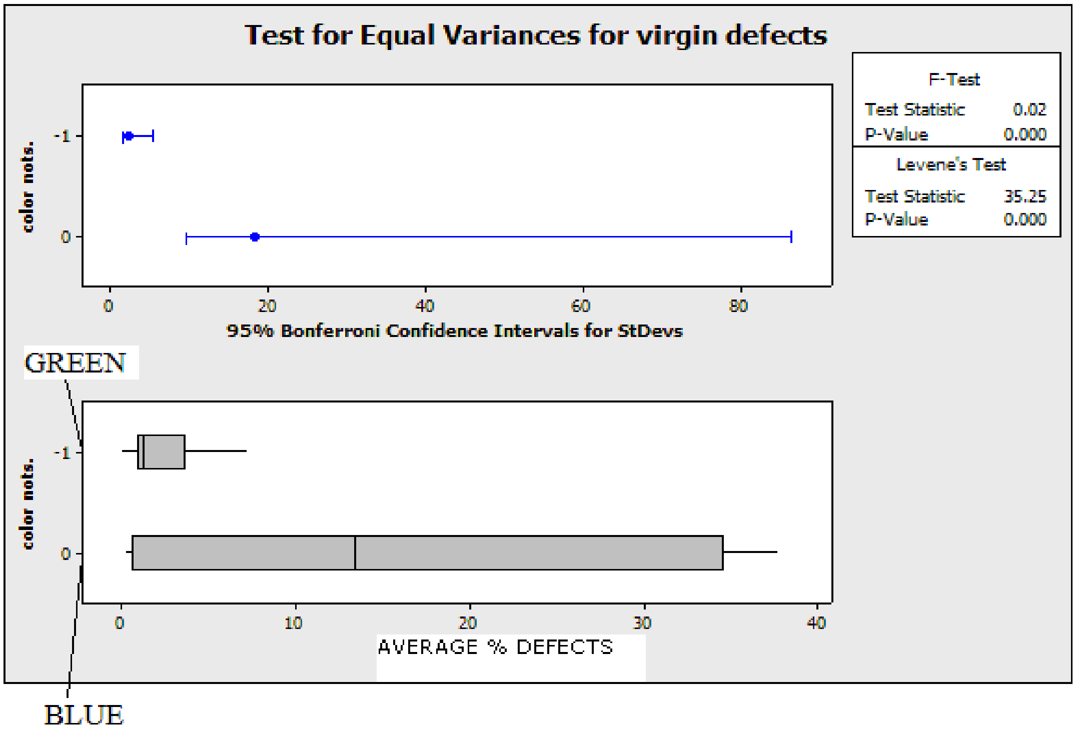


Fig. 5c Test for Equal Variances for Virgin Green vs. Virgin Blue

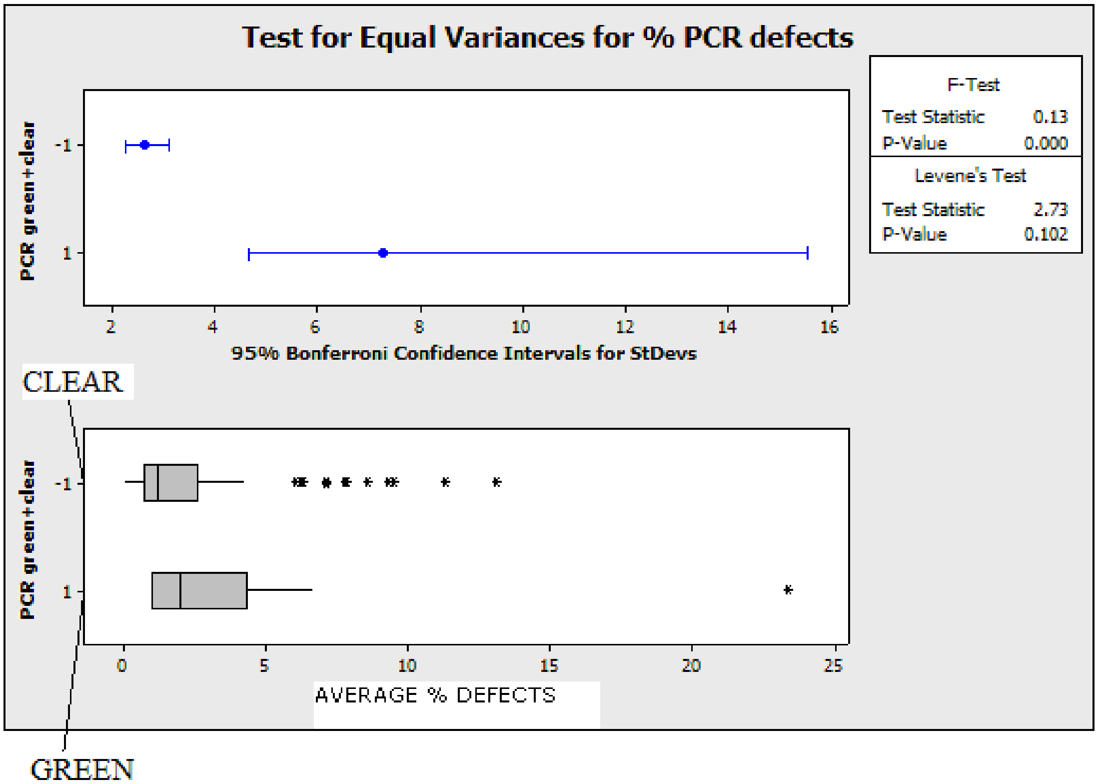


Fig. 6c Test for Equal Variances for PCR Green vs. PCR Clear

Comments: In APPENDIX C, the variance is plotted for the key independent variables and also compares sub-categories within the colored resins. Box plots help for observation simplicities, where the variability is analyzed for the independent variables. The subcategories have been denoted with suitable notations such as -1, 0 and 1 during the MINITAB™ test.