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# Key Factors Affecting Color Reproduction On T-Shirt Fabrics Using Heat Transfer Printing

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Key Factors Affecting Color Reproduction on T-Shirt Fabrics

Using Heat Transfer Printing

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BY

Molly Frank

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# Key Factors Affecting Color Reproduction on T-Shirt Fabrics Using Heat Transfer Printing

Molly Frank

Eastern Illinois University

Spring 2011

# Abstract

Dye sublimation heat transfer printing is commonly used to transfer an image to fabric for small production runs. This process is very inexpensive and is very quick. Unlike digitally printing on fabric, there is no need to treat the fabric once the image has been transferred onto it. Heat transfer printing is also commonly used due to the fact that three different factors can be controlled while printing. These three factors are the temperature, the dwell time, and the pressure. Color reproduction is easy to do once the correct combination of these three factors is found. The temperature, time, and pressure can all be adjusted on the press to assure you are getting the same results every time you transfer an image. This experiment was done in order to figure out which factors influence color reproduction the most on 100% cotton fabric, 50/50 cotton/polyester blend fabric, and 100% polyester fabric. It determined the optimum operating conditions for each type of fabric so that the maximum yield of color gamut, optical density, and print contrast were found. Based on common printing times, temperatures, and pressures for each fabric, the experiment tested each fabric using a randomized $2^3$ factorial design with each of the three factors having a high level (1) and a low level (-1). This experiment contained three independent variables which were the dwell time in the heat zone ($X_1$), the temperature at which the image was transferred ($X_2$), and the pressure of the heat press ($X_3$). The dependent variable (Y) was how well the color was able to be reproduced on each fabric and was measured using the optical density, gamut volume, and print contrast. Although the blend and cotton fabrics were found to be fairly inconsistent in the data collected, the best treatment combination for the blend fabric would be -1,1,1 and the best treatment combination for the cotton fabric would be 1,1,1.

The polyester fabric was the best for this test and proved to be more consistent with a best treatment combination of 1,1,1. For the blend and cotton fabrics, the most dominant effect was the pressure, but for the polyester fabric, the most dominant effect was the dwell time.

## Acknowledgments

I would like to thank my committee: Dr. Yu-Ju Wu, chair; Dr. Rigoberto Chinchilla; and Dr. Luke Steinke. A very special thanks goes to my chair, Dr. Wu for all of her help and support throughout all of the research and it was an honor to work under her supervision. A special thanks goes to Dr. Chinchilla for all of his help with the analysis portion of the research. A special thanks goes to Dr. Steinke for his willingness to serve on my committee and all of his support through the whole process. Since the research was done in the School of Technology at Eastern Illinois University, I would like to thank the department for the equipment and supplies they let me use for my research.

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# Chapter 1

## Introduction

Heat transfer printing is the process of transferring an image from a special transfer paper onto substrates. The image is first printed out on a dye sublimation printer onto paper specially coated for transferring when heat is applied. The image is then transferred to the textiles using a heat transfer press. This research was done to determine the key factors affecting color reproduction when using heat transfer printing on three different types of t-shirt fabrics. The fabrics used were 100% cotton, 50/50 cotton/polyester blend, and 100% polyester, which are all commonly used for many things such as apparel and decorative purposes. These fabrics all have different properties, so this research determined the optimum operating conditions for the process in order to get the maximum color gamut, optical density, and print contrast possible for each type of fabric. Each type of fabric had to be printed using different times, temperatures, and pressures due to the differences in properties of the fabrics. For each factor, there was a high level (1) and a low level (-1) which were determined based on the common settings used for each type of fabric. Test charts were created for the fabric, and after the test charts were heat transferred using the different treatment combinations (a randomized $2^3$ factorial design) of time, temperature, and pressure, the samples were measured using the X-Rite i1iO spectrophotometer. Color gamut was used to investigate color reproduction of certain colors on fabric using heat transfer, so an ICC profile was generated based on the measured L*a*b values of each of the fabrics. Fabric was then heat transferred with an image using the ICC profiles in order to see which image looked the best to outside viewers. In order to evaluate the color reproduction, the gamut

volume, optical density, and print contrast were measured and observed to conclude how well the colors were reproduced.

## Statement of the Purpose

Color is hard to reproduce when using different devices due to the differences in the imaging devices. The purpose of this study was to observe the color reproduction on t-shirt fabrics (100% cotton, 50/50 cotton/polyester blend, and 100% polyester) using heat transfer printing and find the optimum operating conditions for each type of fabric. The time, temperature, and the pressure were controlled using eight different treatment combinations in order to see what the best combination was.

## Statement of the Problem

How was the color reproduction affected on the three different fabrics when the time, temperature, and pressure were controlled during heat transfer? What combination of time, temperature, and pressure gave the best color reproduction based on the evaluation of the color gamut, optical density, and print contrast?

## Questions

Was the quality of color reproduction better with a higher temperature or a lower temperature? Was the quality of color reproduction better with a higher pressure or a lower pressure? Was the quality of color reproduction better with a longer time or a shorter time? Did the interaction between two or three of the variables have a greater impact on color reproduction than just a single factor? Which combination of the three variables was the overall best?

## Hypotheses

The three independent variables of this study were dwell time ($X_1$), temperature ($X_2$), and pressure ($X_3$). The dependent variables (Y) were the color gamut, optical density, and print contrast. The full regression model containing all of the main effects and interaction terms is listed below:

$$\hat{Y}=\alpha+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_1X_2+\beta_5X_1X_3+\beta_6X_2X_3+\beta_7X_1X_2X_3+\varepsilon \qquad \text{Equation 1}$$

The general hypotheses for this study are described below:

### Null Hypothesis

The mean effects of dwell time, temperature, and pressure on the color gamut did not significantly differ from zero; that is,

$H_{0\text{-Color Gamut}}$: $\beta_i=0$, where $i=1,2,3,\ldots,7$.

### Alternative Hypothesis

The mean effects of dwell time, temperature, and pressure on the color gamut significantly differed from zero; that is,

$H_{a\text{-Color Gamut}}$: at least one of the $\beta_i$ not equal to zero.

# Chapter 2

## Related Literature

The heat transfer printing process begins by first printing an image onto a transfer paper using transfer disperse dyes and then transferring that image onto a different substrate using a heat transfer process. This process was started in 1965 and is now used for about 6% of all the textile printing. This type of printing is used mainly for sample printing in order to help in the design selection and the production process. It can also be used for small production runs which include things such as banners, flags, sportswear, and many other items (Siemensmeyer, Provost, Raulfs, & Weiser, 2001). Fabrics can be heat transferred with different designs to make them very unique (Kiseleva, Zubkova, Levakova, & Gorynina, 2006). Due to the process being simple, cheap to use, easy to use to reproduce color, and no post treatment needed, this process has its advantages when looking for a quick and easy way to print on fabrics (Hunting, Derby, Puffer, & Loomie, 1999; Shirai, 1999). There are three phases involved in the heat transfer process which are: a) the ink printed on the paper, (b) a vapor phase transfer of the ink, and (c) the substrate that will receive the ink (Siemensmeyer, et al., 2001). There are also three factors that can be controlled when heat transferring an image to textiles. These three things are temperature at which the image is transferred, the dwell time in the heat zone, and the amount of pressure the press will use. These factors have to be adjusted according to the type of fabric used in the process. When these three factors are correctly set, the image should come out just like it looks on the paper and should be durable (Shirai, 1999; Davis, 2001; Hunting, et al., 1999).

Cotton fabric's most common and well-known use is its use in textiles and clothing apparel. Some of the best properties of cotton fabric include its high absorbency, its resistance to heat, its resistance to static, and its strength and stability. Many times, cotton is combined with other fabrics in order to give it even better properties and to cut down on the cost of the cotton fabric (Charankar, Verma, & Gupta, 2007). While clothing is the most common use of cotton, it is used for other things as well. Cotton is also being used in carpeting and rugs because it is easy to dye and wears better than some of the other fabrics commonly used for carpeting (Rozelle, 1997).

Polyester fabric can also be used for many different things. Some of the most popular uses of it include decorative purposes (including blinds, curtains, draperies, tablecloths, and banners), upholstery (furniture) purposes, and even for clothing (Kiseleva, et al., 2006). Some of the best properties of polyester fabric include its strength, stability, and resistance to wrinkling (Charankar, et al., 2007). Of all the polyester that is printed, a third of it is done using heat transfer printing (Siemensmeyer et al., 2001). Polyester fabric can come in different surface densities and thicknesses and can actually be combined with other materials to make fabric. For this study, 100% polyester fabric was used as well as a blend of 50% cotton fabric and 50% polyester fabric. One problem with polyester fabric is that it is highly flammable (Kiseleva, et al., 2006).

When cotton and polyester are combined, great results are achieved. A cotton/polyester blend is many times ideal "for satisfactory wash and wear purpose, fabrics for rain wear, tailored clothing, dress shirts, and sport shirts" (Charankar, et al., 2006, p.207). The polyester fabric helps keep the shape of the shirt and keep it from

wrinkling. The cotton fabric is used for its comfort and absorbency. Although polyester and cotton fabrics can be combined in different proportions, the one used for this study was a 50/50 blend of polyester and cotton. This combination makes the fabric softer and more absorbent than some of the other combinations, but it also makes it lose some of its strength that would be present with more polyester (Charankar, et al., 2006).

Heat transfer printing uses a special type of paper known as transfer paper for transferring the image to the final substrate. Transfer paper is coated in order to help the paper withstand the high temperatures and high pressures used in heat transfer printing. Elsayad and El-sherbiny (2008) stated:

> Papers are coated in order to improve their surfaces and thus their performance during printing. Among the most important properties of coated paper are a smooth surface, high opacity, high brightness, sufficient mechanical strength to withstand the stresses of printing, and a pore structure that interacts productively with printing ink. (p. 123)

All of these properties of coated paper help to enhance the transfer process and can also contribute to better color reproduction. These are influenced because of the better acceptance of the ink on the coated paper and better releasing of the ink onto the substrate when heat transferred (Elsayad & El-sherbiny, 2008).

The treated paper used for heat transfer is found to have better ink holdout, improved ink tone and gloss reproduction, and ink absorption that is more uniform than uncoated paper. This type of paper is made to release as much of the ink as possible onto the object that is being printed on using heat transfer. This type of paper must be used because regular printing paper is made to absorb and hold the ink in on the paper, so it

would not work to transfer the image to the object being printed (Elsayad & El-sherbiny, 2008). The paper for heat transfer has to be printed on a certain kind of printer. The printer uses dye sublimation inks that transfer to the transfer paper. The interaction between the ink and the paper receiving the ink is important to the quality of the image that will be transferred on an item (Egashira, 2000). There have been tests done to see exactly which type of paper and which dye transfers the color best (Siemensmeyer et al., 2001).

In the color reproduction process, it is difficult to match colors from one device to another, due to differences in each imaging device (Sharma, 2004). Because of this difficulty, color management is very important when printing. In an attempt to get the correct colors when printing, Color Management System (CMS) needs to be incorporated into the process which helps control the color conversion from one device to another (Suchy, Fleming III, & Sharma, 2005). Once printed, the colors need to be evaluated as to whether or not the color reproduction is acceptable to the client. The device often used to check the color reproduction is a color spectrophotometer. This device looks into the formation of color in the polyester material in order to get a good look at color reproduction. Many studies have been done using a color spectrophotometer to take measurements and then put that information into other programs to evaluate the color reproduction. These studies show the spectral behaviors of the inks on the substrate such as the absorption properties of each color, shade, brightness, etc. (Zarubina, Zavadskaya, & Telegin, 2004).

In this study, the results of color reproduction capability of heat transfer on 100% cotton, 50/50 cotton/polyester blend, and 100% polyester fabrics were interpreted in

terms of color gamut volume, optical density, and print contrast. The color gamut is the range of colors that a particular combination of printer, ink, and print media can achieve. Higher volumes indicate the possibility of making more color combinations. Colors outside of the device's capable gamut will not be able to be reproduced (Vrhel & Trussell, 1999). Gamut volume can be measured using the measurements from the spectrophotometer and ColorThink 3.0 Pro Software.

Optical density is also known as solid ink density. This measures how much light is absorbed in a color in order to see how much ink is transferred. The correct amount of ink needs to be transferred to the paper in order to get the results that are desired. Usually, the darker an image looks to the eye, the higher its density. The higher the solid ink density is, the more the midtone gained in density. Shadows tend to get denser and have less contrast when the midtone is darker. When the right amount of ink is transferred, the image will have a high contrast without flattening the shadow contrast (Southworth & Southworth, 1989).

Print contrast (PC) is the comparison of the density of a color at 75% to that of the same color at 100% (Lanzerotti & Balas, 1999). The print contrast is a measure of the shadow contrast and the detail that can be seen in the shadows. It is also commonly used to identify the print quality of printers. Print contrast can be evaluated using the following equation:

$$\% PC = \frac{Ds - Dt}{Ds} \times 100 \qquad \text{Equation 2}$$

Ds = Density of the solid patch (including paper density)
Dt = Density of the three-quartertone patch (including paper density)

Print contrast is used to point out the image tone reproduction at a significant point in the tone curve (Fenster, 1999). According to Lanzerotti and Balas (1999), “good print contrast indicates a printing system’s ability to hold open the shadow areas while still maintaining high solid saturation (density)” (p. 5).

# Chapter 3

## Research Method

This research was done to determine the key factors that affect the color reproduction on 100% cotton, 50/50 cotton/polyester blend, and 100% polyester fabrics using heat transfer printing. Heat transfer took place using the $2^3$ factorial design (table 1a & 1b) by combining the high (1) and low (-1) levels of each factor for the three fabrics. The factorial design was used for this experiment because it was studying the effects of three factors ($X_1$, $X_2$, and $X_3$) and there were two different levels for each factor (-1 and 1). Also, it looked at not only the main effects but also the interactions of the factors which can easily be done using the $2^3$ factorial design (Montgomery, 2005).

Table 1a: *$2^3$ Factorial Design for 100% Polyester*

| | Long Dwell Time | | Short Dwell Time | |
|---|---|---|---|---|
| | Low Temperature | High Temperature | Low Temperature | High Temperature |
| Low Pressure | | | | |
| High Pressure | | | | |
| Factors | Factor Level | | | |
| | -1 | | 1 | |
| Dwell Time ($X_1$) | 30 Seconds | | 40 Seconds | |
| Temperature ($X_2$) | 400°F | | 420°F | |
| Pressure ($X_3$) | 60 psi | | 100 psi | |

Table 1b: *$2^3$ Factorial Design for 100% Cotton & 50/50 Blend*

| | Long Dwell Time | | Short Dwell Time | |
|---|---|---|---|---|
| | Low Temperature | High Temperature | Low Temperature | High Temperature |
| Low Pressure | | | | |
| High Pressure | | | | |
| Factors | Factor Level | | | |
| | -1 | | 1 | |
| Dwell Time ($X_1$) | 25 Seconds | | 35 Seconds | |
| Temperature ($X_2$) | 380°F | | 400°F | |
| Pressure ($X_3$) | 60 psi | | 100 psi | |

## Equipment, Software, and Materials

Table 2: *Equipment, Software, and Materials Used in Research*

| **Equipment, Software, and Materials Used** | |
|---|---|
| Fabric | 100% Cotton Fabric,<br>50/50 Cotton/Polyester Blend Fabric<br>100% Polyester Fabric |
| Heat Transfer Paper | EZ Trans Heat Transfer Paper (100% Polyester)<br>i-Trans Heat Transfer Paper (100% Cotton & 50/50 Blend) |
| Printer | Epson Stylus Pro 4880 Printer with dye sublimation inks |
| Press | Heat Transfer Press: DC16AP Press from Geo Knight & Co. Inc. |
| Measuring Device | X-Rite i1iO Spectrophotometer (D65 illuminant/10°standard observer)<br>X-Rite 530 Spectrophotometer (D65 illuminant/10°standard observer) |
| ICC Profile Generation | MeasureTool Software<br>ProfileMaker Pro 5.0.8 |
| Color Reproduction Evaluation | ColorThink 3.0 Pro |

Procedure

The process began by creating a test chart to be heat transferred onto the three types of fabric. MeasureTool was used to generate the test chart. The test chart was designed for use with the X-Rite i1iO instrument. The reference file used was TC2.83RGBi1_iO.txt. Also on the test chart, was a strip of CMYK (Cyan, Magenta, Yellow, and Black) at 100% (left) and a strip at 75% (right) that were used to observe the density and the print contrast (Figure 1).

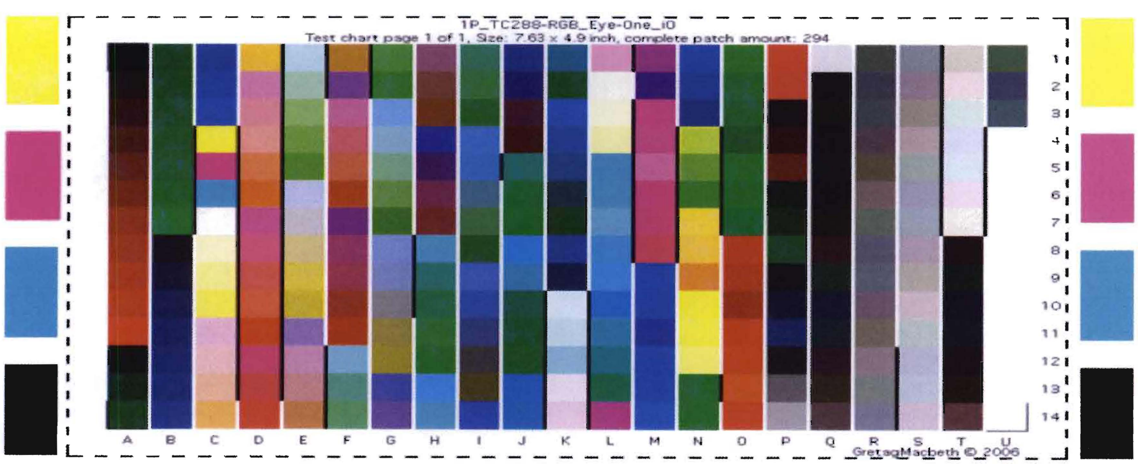


*Figure 1.*Test Chart

The next step in the process was to begin the steps needed to heat transfer the image onto the three types of fabric. Using the Epson Stylus Pro 4880 printer with dye sublimation inks, the test chart was printed on the coated side of the EZ Trans Heat Transfer Paper (used for 100% Polyester) and the iTrans Heat Transfer Paper (used for 100% Cotton and 50/50 blend). The media type was set as Premium Luster Photo Paper (260) for the EZ Trans Paper and UltraSmooth Fine Art Paper for the iTrans paper. They were printed using the mirror image so it would come out correct when heat transferred. The image was printed with no color management and 40 test charts were printed for each type of fabric. Using the Heat Transfer Press, the test charts were heat transferred to the fabric. Five samples were heat transferred at each of the combinations for each fabric so the average could be taken for more accurate results. The temperature, time, and pressure were set at eight different combinations using the factorial design in order to see which combination yielded the best color reproduction for each type of fabric.

Then measurements were taken in order to create ICC profiles for each of the combinations of time, temperature, and pressure. Using MeasureTool with X-Rite i1iO spectrophotometer, each piece of fabric was measured and saved in one folder. The average of the five measurements for each of the eight combinations for each fabric was found. Next, the ICC profiles were created using ProfileMaker. An ICC Profile was created for each of the three types of fabric using the average measurements of the eight combinations. Measurements were also taken of each of the 100% CMYK patches and the 75% CMYK patches using the X-rite 530 spectrophotometer. The densities of these were recorded in order to evaluate the mean density and print contrast of each fabric and combination.

Once ICC profiles had been created, a full color image (Figure 2) was printed onto heat transfer paper to be used for a visual assessment survey.

*Figure 2.*Image Used for Visual Assessment

In order to print the image, color management was applied to the image using the Adobe 1998 profile in Photoshop and then the image was converted to the correct ICC profile. There needed to be 1 image printed for each of the eight different ICC profiles for the three types of fabric that were transferred to the corresponding fabric. Then, using the heat transfer press at the correct combinations of time, temperature, and pressure, each type of fabric was heat transferred for each combination. The ICC profile that was used for each sample should have been created using the same time, temperature, and pressure combination that the heat transfer press was set to while printing. These images were then viewed by others in order to see which looked the best and see if the conclusions of the optimum operating conditions matched the image that others thought looked the best. The

subjects were given a survey (Appendix A) to fill out and rank the eight images from one to eight with one being the best quality and eight being the worst. Twenty-seven surveys were handed out to random subjects and the results were used to compare the naked eye to the actual measured results.

## Analysis

Color measurements were taken using the X-rite i1iO Spectrophotometer using illuminant D65 and a 10-degree observer for textile prints. ICC profiles were generated using these measurements in ProfileMaker Pro 5.0.8. Then, in order to analyze the information, the color gamut of the samples was observed. To do this, CHROMiX ColorThink 3.0 Pro was used and the gamut volumes of the average measurements of the pieces of fabric were observed and recorded. Also for analysis, the optical density was evaluated as well as the print contrast.

The print contrast was evaluated based on the measurements of the 75% CMYK patches compared to the measurements of the 100% CMYK patches that were taken using the X-rite 530 Spectrophotometer. Tables 3a & 3b were used to record the data and DOE Pro XL was used to analyze the data by performing ANOVA and regression analyses.

Table 3a: *The Mean Optical Densities, Gamut Volume, & Print Contrasts for the Eight Runs (100% Polyester)*

| No | Factor $X_1$ | $X_2$ | $X_3$ | Treatment Combination | Run Order | Mean Density of Y | Mean Density of M | Mean Density of C | Mean Density of K | Mean Gamut Volume | Print Contrast of Y | Print Contrast of M | Print Contrast of C | Print Contrast of K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | 3 | | | | | | | | | |
| 2 | 1 | -1 | -1 | a | 4 | | | | | | | | | |
| 3 | -1 | 1 | -1 | b | 2 | | | | | | | | | |
| 4 | 1 | 1 | -1 | ab | 1 | | | | | | | | | |
| 5 | -1 | -1 | 1 | c | 6 | | | | | | | | | |
| 6 | 1 | -1 | 1 | ac | 8 | | | | | | | | | |
| 7 | -1 | 1 | 1 | bc | 7 | | | | | | | | | |
| 8 | 1 | 1 | 1 | abc | 5 | | | | | | | | | |

| Factor | Factor Level -1 | 1 |
|---|---|---|
| $X_1$: Dwell Time | 30 seconds | 40 seconds |
| $X_2$: Temperature | 400°F | 420°F |
| $X_3$: Pressure | 60 psi | 100 psi |

Table 3b: *The Mean Optical Densities, Gamut Volume, & Print Contrasts for the Eight Runs (100% Cotton and 50/50 Blend)*

| No | Factor $X_1$ | $X_2$ | $X_3$ | Treatment Combination | Run Order | Mean Density of Y | Mean Density of M | Mean Density of C | Mean Density of K | Mean Gamut Volume | Print Contrast of Y | Print Contrast of M | Print Contrast of C | Print Contrast of K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | 3 | | | | | | | | | |
| 2 | 1 | -1 | -1 | a | 4 | | | | | | | | | |
| 3 | -1 | 1 | -1 | b | 2 | | | | | | | | | |
| 4 | 1 | 1 | -1 | ab | 1 | | | | | | | | | |
| 5 | -1 | -1 | 1 | c | 6 | | | | | | | | | |
| 6 | 1 | -1 | 1 | ac | 8 | | | | | | | | | |
| 7 | -1 | 1 | 1 | bc | 7 | | | | | | | | | |
| 8 | 1 | 1 | 1 | abc | 5 | | | | | | | | | |

| Factor | Factor Level -1 | 1 |
|---|---|---|
| $X_1$: Dwell Time | 25 seconds | 35 seconds |
| $X_2$: Temperature | 380°F | 400°F |
| $X_3$: Pressure | 60 psi | 100 psi |

The next step in the analysis was to test the equations to see how accurate they were. This was done by choosing six random equations out of the twenty-six total equations. Six test charts were printed out and heat transferred at the best treatment combination for each equation. The six samples were measured using the X-rite i1iO Spectrophotometer and ICC profiles were generated using ProfileMaker Pro 5.0.8. Using CHROMiX ColorThink 3.0 Pro, the gamut volumes were observed and recorded for the equation(s) dealing with color gamut. The average gamut volume of the six samples was taken and compared to the target value (shown in Table 4) to see how accurate the equation was. For the equations dealing with the density of an ink color, that ink color

patch at 100% was measured using the X-rite 530 Spectrophotometer and the density was recorded. The average density was then taken and compared to the target value for that equation in order to see how accurate the equation was. Finally, any equations dealing with the print contrast of an ink color were tested by measuring the patches of that color at both 100% and 75% and then evaluated using the equation for print contrast. The average print contrast was then taken and compared to the target value to see how accurate the equation was.

Table 4: *Target Values for the Dependent Variables for Each Fabric*

| | Density | | | | Print contrast | | | | Color |
|---|---|---|---|---|---|---|---|---|---|
| | C | M | Y | K | C | M | Y | K | Gamut |
| Polyester | 1.60 | 1.50 | 1.00 | 1.50 | 16.60 | 15.70 | 31.00 | 9.60 | 321050.00 |
| Blend | 1.40 | 1.50 | 0.90 | 1.50 | 11.70 | 17.80 | 32.20 | 21.00 | 274100.00 |
| Cotton | 1.30 | 1.50 | 0.80 | 1.50 | | 19.70 | 29.80 | 20.50 | 243400.00 |

# Chapter 4

## Results and Discussion

Tables 5a, 5b, and 5c summarize the factors, factor levels, run order, treatment combinations, solid ink densities of yellow, magenta, cyan, and black, gamut volume, and print contrast of yellow, magenta, cyan, and black for 100% polyester, 50/50 cotton/polyester blend, and 100% cotton fabrics respectively. The data from these three tables was used to perform the factorial analysis, regression analysis, and ANOVA analysis. Table 5c is lacking the data for the print contrast of C for the cotton fabric because the data was not normal. Negative values were calculated which is possibly due to color shift. Future research could be done to figure out exactly why negative values were measured for this attribute but not any other attributes or any other fabrics.

Table 5a: *The mean optical densities, gamut volume, and print contrasts for the eight runs (100% Polyester)*

| No | Factor $X_1$ | Factor $X_2$ | Factor $X_3$ | Treatment Combination | Run Order | Mean Density of Y | Mean Density of M | Mean Density of C | Mean Density of K | Mean Gamut Volume | Print Contrast of Y | Print Contrast of M | Print Contrast of C | Print Contrast of K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | 2 | 0.80 | 1.22 | 1.43 | 1.31 | 256599 | 21 | 6.4 | 9.6 | 9.6 |
| 2 | 1 | -1 | -1 | a | 1 | 0.892 | 1.344 | 1.506 | 1.372 | 297938 | 27.2 | 11.4 | 11.4 | 6.6 |
| 3 | -1 | 1 | -1 | b | 8 | 0.864 | 1.284 | 1.466 | 1.334 | 271917 | 27.8 | 10 | 12.6 | 7.6 |
| 4 | 1 | 1 | -1 | ab | 7 | 0.916 | 1.368 | 1.52 | 1.422 | 311286 | 30.6 | 10.4 | 13.6 | 7.6 |
| 5 | -1 | -1 | 1 | c | 5 | 0.828 | 1.244 | 1.45 | 1.288 | 267382 | 23.6 | 8.6 | 12 | 7.8 |
| 6 | 1 | -1 | 1 | ac | 3 | 0.912 | 1.37 | 1.504 | 1.384 | 307064 | 29.4 | 12.6 | 12.6 | 6.4 |
| 7 | -1 | 1 | 1 | bc | 6 | 0.894 | 1.344 | 1.504 | 1.394 | 294971 | 29 | 11.4 | 13.4 | 8.4 |
| 8 | 1 | 1 | 1 | abc | 4 | 0.926 | 1.464 | 1.546 | 1.446 | 321016 | 30.6 | 15.6 | 16.6 | 8 |

| Factor | Factor Level -1 | Factor Level 1 |
|---|---|---|
| $X_1$: Dwell Time | 30 seconds | 40 seconds |
| $X_2$: Temperature | 400°F | 420°F |
| $X_3$: Pressure | 60 psi | 100 psi |

Table 5b: *The mean optical densities, gamut volume, and print contrasts for the eight runs (50/50 Blend)*

| No | Factor $X_1$ | Factor $X_2$ | Factor $X_3$ | Treatment Combination | Run Order | Mean Density of Y | Mean Density of M | Mean Density of C | Mean Density of K | Mean Gamut Volume | Print Contrast of Y | Print Contrast of M | Print Contrast of C | Print Contrast of K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | 2 | 0.782 | 1.394 | 1.262 | 1.444 | 246101 | 28.4 | 15.6 | 5 | 15.4 |
| 2 | 1 | -1 | -1 | a | 1 | 0.82 | 1.454 | 1.308 | 1.484 | 244626 | 28.6 | 17.8 | 6 | 19.8 |
| 3 | -1 | 1 | -1 | b | 8 | 0.812 | 1.444 | 1.32 | 1.456 | 252324 | 26.6 | 15.4 | 7.6 | 20.8 |
| 4 | 1 | 1 | -1 | ab | 7 | 0.822 | 1.414 | 1.302 | 1.45 | 252813 | 32.2 | 15.4 | 6.6 | 16.8 |
| 5 | -1 | -1 | 1 | c | 5 | 0.826 | 1.464 | 1.288 | 1.456 | 268068 | 29.4 | 15.4 | 6.6 | 14.6 |
| 6 | 1 | -1 | 1 | ac | 3 | 0.844 | 1.462 | 1.36 | 1.456 | 272593 | 30.4 | 15 | 11.4 | 16.2 |
| 7 | -1 | 1 | 1 | bc | 6 | 0.832 | 1.484 | 1.358 | 1.486 | 274109 | 30 | 15.8 | 11.4 | 18 |
| 8 | 1 | 1 | 1 | abc | 4 | 0.85 | 1.482 | 1.36 | 1.474 | 267983 | 30.6 | 16.8 | 11.6 | 15.6 |

| Factor | Factor Level -1 | Factor Level 1 |
|---|---|---|
| $X_1$: Dwell Time | 25 seconds | 35 seconds |
| $X_2$: Temperature | 380°F | 400°F |
| $X_3$: Pressure | 60 psi | 100 psi |

Table 5c: *The mean optical densities, gamut volume, and print contrasts for the eight runs (100% Cotton)*

| No | Factor $X_1$ | Factor $X_2$ | Factor $X_3$ | Treatment Combination | Run Order | Mean Density of Y | Mean Density of M | Mean Density of C | Mean Density of K | Mean Gamut Volume | Print Contrast of Y | Print Contrast of M | Print Contrast of K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | 2 | 0.706 | 1.402 | 1.118 | 1.414 | 222076 | 24.4 | 15.4 | 11.6 |
| 2 | 1 | -1 | -1 | a | 1 | 0.692 | 1.398 | 1.102 | 1.436 | 215741 | 20.6 | 18.8 | 20.4 |
| 3 | -1 | 1 | -1 | b | 8 | 0.696 | 1.386 | 1.126 | 1.418 | 227037 | 24.4 | 16.6 | 18.8 |
| 4 | 1 | 1 | -1 | ab | 7 | 0.708 | 1.426 | 1.106 | 1.354 | 215801 | 28.2 | 16.2 | 15.4 |
| 5 | -1 | -1 | 1 | c | 5 | 0.688 | 1.442 | 1.176 | 1.466 | 240060 | 21.4 | 15.6 | 18.6 |
| 6 | 1 | -1 | 1 | ac | 3 | 0.726 | 1.432 | 1.166 | 1.45 | 235260 | 26 | 16.6 | 17.4 |
| 7 | -1 | 1 | 1 | bc | 6 | 0.718 | 1.456 | 1.192 | 1.444 | 243391 | 24.6 | 17.8 | 17.6 |
| 8 | 1 | 1 | 1 | abc | 4 | 0.756 | 1.456 | 1.204 | 1.442 | 242760 | 29.6 | 19.6 | 18.6 |

| Factor | Factor Level -1 | Factor Level 1 |
|---|---|---|
| $X_1$: Dwell Time | 25 seconds | 35 seconds |
| $X_2$: Temperature | 380°F | 400°F |
| $X_3$: Pressure | 60 psi | 100 psi |

## ANOVA & Regression Analysis

The results of the ANOVA and Regression analyses look at the main effects of the independent variables ($X_1$, $X_2$, and $X_3$) and their interaction effects ($X_1X_2$, $X_1X_3$, $X_2X_3$, and $X_1X_2X_3$) on the dependent variables (density of CMYK, gamut volume, and print contrast of CMYK). The significant level was set at 0.05 for all of the analyses. The full model from the $2^3$ factorial design is:

$$\hat{Y}=\alpha+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_1X_2+\beta_5X_1X_3+\beta_6X_2X_3+\beta_7X_1X_2X_3+\varepsilon \qquad \text{Equation 3}$$

Where $X_1$=dwell time; $X_2$=temperature; $X_3$=pressure.

The significant effects were selected from the full model by the factorial analysis procedure using DOE Pro XL for each of the dependent variables. Only the significant effects were included in the reduced model for the regression analysis, factorial analysis, and ANOVA analysis. Due to the size of the full charts, only the summarized results were included in this paper organized into the following parts or the observed attributes (for full ANOVA tables, see Appendix B):

1. the significant effects that would be included in the reduced model and their percentage of contribution,
2. the best prediction equation involving all the significant effects in the reduced model in order to obtain the best operating conditions for each type of fabric and each attribute,
3. the best treatment combinations, including their levels, to obtain the maximum density, color gamut, or print contrast for that type of fabric,
4. the estimated maximum value to be obtained using the best treatment combinations and the prediction equations,
5. the target values for each attribute, which are set as the goal value when transferring the image, and
6. the difference between the estimated maximum value and the target value used to see if the target can be obtained based on the equation.

The summary results of the ANOVA and Regression analyses for the main and interaction effects on the color gamut, density for CMYK, and print contrast for CMYK are shown in Tables 6a through 6g.

Table 6a: *ANOVA and Regression Summary for Color Gamut of 50/50 Blend, 100% Polyester, and 100% Cotton Fabrics*

| Color Gamut | | | |
|---|---|---|---|
| | Blend | Polyester | Cotton |
| Sig. Level | α=0.05 | α=0.05 | α=0.05 |
| Significant Effects | $X_3$=91.92%<br>$X_2$=3.06%<br>$X_2X_3$=2.05%<br>$X_1X_2X_3$=1.94%<br>$X_1X_2$=0.92%<br>$X_1$=0.08% | $X_1$=70.48%<br>$X_2$=16.20%<br>$X_3$=9.13%<br>$X_1X_2$=0.80%<br>$X_1X_3$=0.74%<br>$X_2X_3$=0.54%<br>$X_1X_2X_3$=0.45% | $X_3$=86.16%<br>$X_1$=6.98%<br>$X_2$=3.31%<br>$X_1X_3$=1.94%<br>$X_1X_2X_3$=1.09%<br>$X_2X_3$=0.45% |
| Prediction Equation (Y) | $259827.1-323.13X_1+1980.13X_2+10861.2X_3-1085.73X_1X_2-1622.48X_2X_3-1576.93X_1X_2X_3$ | $291021.6+18304.3X_1+8775.83X_2+6586.73X_3-1951.08X_1X_2-1872.58X_1X_3+1609.18X_2X_3-1458.33X_1X_2X_3$ | $230265.7-2875.15X_1+1981.55X_2+10102.1X_3+1517.6X_1X_3+726.3X_2X_3+1133.85X_1X_2X_3$ |
| Best Treatment Combination | $X_1$=25 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(-1,1,1) | $X_1$=40 sec<br>$X_2$=420°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=25 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(-1,1,1) |
| Estimated Max. Value | 274031.74 | 321015.65 | 243299.35 |
| Target Value | 274100.00 | 321050.00 | 243400.00 |
| Difference | 68.26 | 34.35 | 100.65 |

Based on Table 6a, it is shown that the dominant effect on the color gamut for the blend and cotton fabrics is $X_3$, which is the pressure applied by the heat transfer press. For the polyester fabric, the most dominant effect is $X_1$, which is the dwell time. Table 6a also shows that the best treatment combination in order to obtain the highest gamut volume for the blend and cotton fabrics is a time of 25 seconds, a temperature of 400°F,

and a pressure of 100 psi (-1,1,1). For the polyester fabric, the best treatment combination to obtain the highest gamut volume is 40 seconds for the time, 420°F for the temperature, and 100 psi for the pressure (1,1,1).

Table 6b: *ANOVA and Regression Summary for Density of 50/50 Blend Fabric*

| Density (Blend) | | | | |
|---|---|---|---|---|
| | C | M | Y | K |
| Sig. Level | $\alpha$=0.05 | $\alpha$=0.05 | $\alpha$=0.05 | $\alpha$=0.05 |
| Significant Effects | $X_3$=38.54%<br>$X_1X_2$=22.86%<br>$X_2$=18.95%<br>$X_1$=13.24%<br>$X_1X_3$=2.69% | $X_3$=59.90%<br>$X_1X_2$=14.02%<br>$X_1X_2X_3$=14.02%<br>$X_2$=4.33%<br>$X_1X_3$=2.00%<br>$X_2X_3$=1.56%<br>$X_1$=1.17% | $X_3$=50.33%<br>$X_1$=26.39%<br>$X_2$=7.24%<br>$X_1X_2$=2.93%<br>$X_1X_2X_3$=2.93%<br>$X_2X_3$=1.50% | $X_2X_3$=31.65%<br>$X_1X_2$=21.73%<br>$X_1X_3$=13.67%<br>$X_3$=9.33%<br>$X_1X_2X_3$=7.47%<br>$X_2$=4.37%<br>$X_1$=3.13% |
| Prediction Equation (Y) | 1.320+0.01275 $X_1$+0.01525 $X_2$+0.02175 $X_3$-0.01675 $X_1X_2$+0.00575 $X_1X_3$-0.00075 $X_1X_2X_3$ | 1.450+0.00325 $X_1$+0.00625 $X_2$+0.02325 $X_3$-0.01125 $X_1X_2$-0.00425 $X_1X_3$+0.00375 $X_2X_3$+0.01125 $X_1X_2X_3$ | 0.8235+0.0105 $X_1$+0.0055 $X_2$+0.0145 $X_3$-0.0035 $X_1X_2$-0.0025 $X_2X_3$+0.0035 $X_1X_2X_3$ | 1.463+0.00275 $X_1$+0.00325 $X_2$+0.00475 $X_3$-0.00725 $X_1X_2$-0.00575 $X_1X_3$+0.00875 $X_2X_3$+0.00425 $X_1X_2X_3$ |
| Best Treatment Combination | $X_1$=35 sec<br>$X_2$=380°F<br>$X_3$=100 psi<br>(1,-1,1) | $X_1$=25 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(-1,1,1) | $X_1$=35 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=25 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(-1,1,1) |
| Estimated Max. Value | 1.36 | 1.48 | 0.85 | 1.49 |
| Target Value | 1.40 | 1.50 | 0.90 | 1.50 |
| Difference | 0.04 | 0.02 | 0.05 | 0.01 |

Based on Table 6b, it is shown that the dominant effect on the density of C, M, and Y for the blend is $X_3$, which is the pressure applied by the heat transfer press. For the density of K for the blend fabric, $X_2X_3$ is the most dominant effect which is the interaction between the temperature ($X_2$) and the pressure ($X_3$). Table 6b also shows that the best treatment combination for the highest density of cyan ink for the blend fabric is a

time of 35 seconds, a temperature of 380°F, and a pressure of 100 psi (1,-1,1). For the magenta and black ink, the best treatment combination is 25 seconds, 400°F, and 100 psi (-1,1,1) and for the yellow ink, the best treatment combination is 35 seconds, 400°F, and 100 psi (1,1,1). Overall, a pressure of 100 psi will yield the maximum density for any of the four colors.

Table 6c: *ANOVA and Regression Summary for Density of 100% Polyester Fabric*

| Density (Polyester) | | | | |
|---|---|---|---|---|
| | C | M | Y | K |
| Sig. Level | α=0.05 | α=0.05 | α=0.05 | α=0.05 |
| Significant Effects | $X_1$=60.53%<br>$X_2$=24.69%<br>$X_3$=7.45%<br>$X_2X_3$=3.06%<br>$X_1X_2$=1.10%<br>$X_1X_3$=1.10% | $X_1$=59.79%<br>$X_2$=22.79%<br>$X_3$=12.70%<br>$X_2X_3$=2.83%<br>$X_1X_2$=0.76%<br>$X_1X_3$=0.37%<br>$X_1X_2X_3$=0.37% | $X_1$=59.54%<br>$X_2$=24.65%<br>$X_1X_2$=7.24%<br>$X_3$=6.62%<br>$X_1X_3$=0.60%<br>$X_1X_2X_3$=0.18% | $X_1$=52.99%<br>$X_2$=35.16%<br>$X_2X_3$=4.71%<br>$X_3$=3.53%<br>$X_1X_2X_3$=2.53%<br>$X_1X_2$=0.28% |
| Prediction Equation (Y) | 1.491+0.02775 $X_1$+0.01775 $X_2$+0.00975 $X_3$-0.00375 $X_1X_2$-0.00375 $X_1X_3$+0.00625 $X_2X_3$ | 1.330+0.0575 $X_1$+0.0355 $X_2$+0.0265 $X_3$-0.0065 $X_1X_2$+0.0045 $X_1X_3$+0.0125 $X_2X_3$+0.0045 $X_1X_2X_3$ | 0.87925+0.03225 $X_1$+0.02075 $X_2$+0.01075 $X_3$-0.01125 $X_1X_2$-0.00325 $X_1X_3$-0.00175 $X_1X_2X_3$ | 1.368+0.03775 $X_1$+0.03075 $X_2$+0.00975 $X_3$-0.00275 $X_1X_2$+0.01125 $X_2X_3$-0.00825 $X_1X_2X_3$ |
| Best Treatment Combination | $X_1$=40 sec<br>$X_2$=420°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=40 sec<br>$X_2$=420°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=40 sec<br>$X_2$=420°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=40 sec<br>$X_2$=420°F<br>$X_3$=100 psi<br>(1,1,1) |
| Estimated Max. Value | 1.55 | 1.46 | 0.93 | 1.45 |
| Target Value | 1.60 | 1.50 | 1.00 | 1.50 |
| Difference | 0.06 | 0.04 | 0.07 | 0.05 |

Based on Table 6c, it is shown that the dominant effect on the density of all four colors for the polyester fabric is $X_1$, which is the dwell time. The temperature ($X_2$) is also pretty significant as it fall second in the contribution percentage for all four colors. Table

6c also shows that the best treatment combination for the highest density of all four color inks for the polyester fabric is 40 seconds for the time, 420°F for the temperature, and 100 psi for the pressure (1,1,1).

Table 6d: *ANOVA and Regression Summary for Density of 100% Cotton Fabric*

| Density (Cotton) | | | | |
|---|---|---|---|---|
| | C | M | Y | K |
| Sig. Level | α=0.05 | α=0.05 | α=0.05 | α=0.05 |
| Significant Effects | $X_3$=88.09%<br>$X_2$=4.69%<br>$X_2X_3$=1.90%<br>$X_1X_3$=1.56%<br>$X_1$=1.24%<br>$X_1X_2X_3$=0.73%<br>$X_1X_2$=0.35% | $X_3$=72.79%<br>$X_1X_2$=7.01%<br>$X_2$=6.01%<br>$X_1X_3$=5.09%<br>$X_1X_2X_3$=2.78%<br>$X_1$=1.63%<br>$X_2X_3$=1.63% | $X_3$=25.63%<br>$X_1X_3$=21.08%<br>$X_1$=18.97%<br>$X_2$=15.09%<br>$X_2X_3$=10.10%<br>$X_1X_2$=2.34%<br>$X_1X_2X_3$=2.34% | $X_3$=48.40%<br>$X_2$=17.42%<br>$X_1X_2X_3$=14.94%<br>$X_1X_2$=7.74%<br>$X_1$=5.38%<br>$X_2X_3$=3.44%<br>$X_1X_3$=0.86% |
| Prediction Equation (Y) | 1.149-0.00425 $X_1$+0.00825 $X_2$+0.03575 $X_3$+0.00225 $X_1X_2$+0.00475 $X_1X_3$+0.00525 $X_2X_3$+0.00325 $X_1X_2X_3$ | 1.425+0.00325 $X_1$+0.00625 $X_2$+0.02175 $X_3$+0.00675 $X_1X_2$-0.00575 $X_1X_3$+0.00325 $X_2X_3$-0.00425 $X_1X_2X_3$ | 0.71125+0.0092 5 $X_1$+0.00825 $X_2$+0.01075 $X_3$+0.00325 $X_1X_2$+0.00975 $X_1X_3$+0.00675 $X_2X_3$-0.00325 $X_1X_2X_3$ | 1.428-0.0075 $X_1$-0.0135 $X_2$+0.0225 $X_3$-0.009$X_1X_2$+0.00 3 $X_1X_3$+0.006 $X_2X_3$+0.0125 $X_1X_2X_3$ |
| Best Treatment Combination | $X_1$=35 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=25/35 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(-1,1,1) (1,1,1) | $X_1$=35 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=25 sec<br>$X_2$=380°F<br>$X_3$=100 psi<br>(-1,-1,1) |
| Estimated Max. Value | 1.20 | 1.46 | 0.76 | 1.47 |
| Target Value | 1.30 | 1.50 | 0.80 | 1.50 |
| Difference | 0.10 | 0.04 | 0.04 | 0.03 |

Based on Table 6d, it is shown that the dominant effect on the density of all four colors for the cotton fabric is $X_3$, which is the pressure applied by the heat transfer press. Table 6d also shows that the best treatment combination for the highest density of cyan and yellow ink for the cotton fabric is a time of 35 seconds, a temperature of 400°F, and a pressure of 100 psi (1,1,1). For the magenta ink, there are two treatment combinations

that both yield the highest density for the cotton fabric. The combinations are a time of either 25 seconds or 35 seconds, a temperature of 400°F, and a pressure of 100 psi (-1,1,1) or (1,1,1). For the black ink, the best treatment combination is 25 seconds, 380°F, and 100 psi (-1,-1,1). Overall, a pressure of 100 psi will yield the maximum density for any of the four colors.

Table 6e: *ANOVA and Regression Summary for Print Contrast of 50/50 Blend Fabric*

| Print Contrast (Blend) | | | | |
|---|---|---|---|---|
| | C | M | Y | K |
| Sig. Level | α=0.05 | α=0.05 | α=0.05 | α=0.05 |
| Significant Effects | $X_3$=53.81%<br>$X_2$=14.49%<br>$X_1X_2$=9.39%<br>$X_1$=5.39%<br>$X_1X_3$=5.39%<br>$X_1X_2X_3$=1.46% | $X_2X_3$=31.58%<br>$X_1X_2X_3$=17.76%<br>$X_1$=10.75% | $X_1$=27.17%<br>$X_1X_2X_3$=16.69%<br>$X_1X_2$=12.40%<br>$X_3$=10.50%<br>$X_1X_3$=8.75%<br>$X_2$=3.35% | $X_1X_2$=51.36%<br>$X_3$=23.57%<br>$X_2$=9.03%<br>$X_1X_2X_3$=6.47% |
| Prediction Equation (Y) | $8.275+0.625 X_1+1.025 X_2+1.975 X_3-0.825 X_1X_2+0.625 X_1X_3-0.325 X_1X_2X_3$ | $15.9+0.35 X_1+0.6 X_2+0.45 X_1X_2X_3$ | $29.525+0.925 X_1+0.325 X_2+0.575 X_3+0.625 X_1X_2-0.525 X_1X_3-0.725 X_1X_2X_3$ | $17.15+0.65 X_2-1.05 X_3-1.55 X_1X_2+0.55 X_1X_2X_3$ |
| Best Treatment Combination | $X_1$=35 sec<br>$X_2$=380°F<br>$X_3$=100 psi<br>(1,-1,1) | $X_1$=35 sec<br>$X_2$=400/380°F<br>$X_3$=100/60 psi<br>(1,1,1) (1,-1,-1) | $X_1$=35 sec<br>$X_2$=400°F<br>$X_3$=60 psi<br>(1,1,-1) | $X_1$=25 sec<br>$X_2$=400°F<br>$X_3$=60 psi<br>(-1,1,-1) |
| Estimated Max. Value | 11.63 | 17.30 | 32.08 | 20.95 |
| Target Value | 11.70 | 17.80 | 32.20 | 21.00 |
| Difference | 0.07 | 0.50 | 0.13 | 0.05 |

Based on Table 6e, it is shown that the dominant effect on the print contrast of the blend fabric differs for all four colors. For the print contrast of C, the dominant effect is $X_3$, which is the pressure applied by the heat transfer press. For the print contrast of M, the dominant effect is $X_2X_3$, which is the interaction between the temperature ($X_2$) and

the pressure ($X_3$). For the print contrast of Y, the dominant effect is $X_1$, which is the dwell time. For the print contrast of K, the dominant effect is $X_1X_2$, which is the interaction between the dwell time ($X_1$) and the temperature ($X_2$). Table 6e also shows that the best treatment combination for the highest print contrast of cyan ink for the blend fabric is a time of 35 seconds, a temperature of 380°F, and a pressure of 100 psi (1,-1,1). For the magenta ink, there are two treatment combinations that both yield the highest print contrast for the blend fabric. The combinations are a time of 35 seconds, a temperature of 400°F, and a pressure of 100 psi (1,1,1) or a time of 35 seconds, a temperature of 380°F, and a pressure of 60 psi (1,-1,-1). For the yellow ink, the best treatment combination is 35 seconds, 400°F, and 60 psi (1,1,-1). For the black ink, the best treatment combination is 25 seconds, 400°F, and 60 psi (-1,1,-1). Since the dominant effects and the best treatment combinations are different, it proves that the print contrast for the blend fabric is not consistent.

Table 6f: *ANOVA and Regression Summary for Print Contrast of 100% Polyester Fabric*

| Print Contrast (Polyester) | | | | |
|---|---|---|---|---|
| | C | M | Y | K |
| Sig. Level | α=0.05 | α=0.05 | α=0.05 | α=0.05 |
| Significant Effects | $X_2$=46.21%<br>$X_3$=22.52%<br>$X_1$=17.91%<br>$X_1X_2X_3$=4.75%<br>$X_1X_2$=1.33% | $X_1$=42.75%<br>$X_3$=23.11%<br>$X_2$=16.31%<br>$X_1X_2X_3$=5.33%<br>$X_1X_2$=4.47%<br>$X_2X_3$=2.37%<br>$X_1X_3$=1.81% | $X_2$=41.06%<br>$X_1$=39.13%<br>$X_1X_2$=8.40%<br>$X_3$=5.24%<br>$X_2X_3$=1.89% | $X_1$=33.10%<br>$X_1X_2$=22.99%<br>$X_2X_3$=14.71%<br>$X_1X_2X_3$=5.75% |
| Prediction Equation (Y) | $12.725+0.825 X_1+1.325 X_2+0.925 X_3+0.225 X_1X_2+0.425 X_1X_2X_3$ | $10.8+1.7 X_1+1.05 X_2+1.25 X_3-0.55 X_1X_2+0.35 X_1X_3+0.4 X_2X_3+0.6 X_1X_2X_3$ | $27.4+2.05 X_1+2.1 X_2+0.75 X_3-0.95 X_1X_2-0.45 X_2X_3$ | $7.75-0.6 X_1+0.5 X_1X_2+0.4 X_2X_3-0.25 X_1X_2X_3$ |
| Best Treatment Combination | $X_1$=40 sec<br>$X_2$=420°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=40 sec<br>$X_2$=420°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=40 sec<br>$X_2$=420°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=30 sec<br>$X_2$=400°F<br>$X_3$=60 psi<br>(-1,-1,-1) |
| Estimated Max. Value | 16.45 | 15.60 | 30.90 | 9.50 |
| Target Value | 16.60 | 15.70 | 31.00 | 9.60 |
| Difference | 0.15 | 0.10 | 0.10 | 0.10 |

Based on Table 6f, it is shown that the dominant effect on the print contrast of C and Y for the polyester fabric is $X_2$, which is the temperature of the heat transfer press. For the print contrast of M and K, the dominant effect is $X_1$, which is the dwell time. Table 6f also shows that the best treatment combination for the highest print contrast of the cyan, magenta, and yellow inks for the polyester fabric is 40 seconds for the time,

420°F for the temperature, and 100 psi for the pressure (1,1,1). For the black ink, the best treatment combination is 30 seconds, 400°F, and 60 psi (-1,-1,-1).

Table 6g: *ANOVA and Regression Summary for Print Contrast of 100% Cotton Fabric*

| Print Contrast (Cotton) | | | |
|---|---|---|---|
| | M | Y | K |
| Sig. Level | α=0.05 | α=0.05 | α=0.05 |
| Significant Effects | $X_2X_3$=30.67%<br>$X_1$=23.68%<br>$X_1X_2X_3$=14.90%<br>$X_2$=10.17%<br>$X_1X_2$=6.34%<br>$X_3$=4.76% | $X_2$=38.62%<br>$X_1$=17.16%<br>$X_1X_3$=17.16%<br>$X_1X_2$=11.92%<br>$X_1X_2X_3$=9.65<br>% $X_3$=2.98% | $X_1X_2X_3$=48.65%<br>$X_1X_2$=23.46%<br>$X_3$=8.45%<br>$X_1X_3$=7.36%<br>$X_1$=6.34%<br>$X_2$=1.35%<br>$X_2X_3$=0.94% |
| Prediction Equation (Y) | 17.075+0.725 $X_1$+0.475 $X_2$+0.325 $X_3$-0.375 $X_1X_2$+0.825 $X_2X_3$+0.575 $X_1X_2X_3$ | 24.9+1.2 $X_1$+1.8 $X_2$+0.5 $X_3$+1.0 $X_1X_2$+1.2 $X_1X_3$-0.9 $X_1X_2X_3$ | 17.3+0.65 $X_1$+0.3 $X_2$+0.75 $X_3$-1.25 $X_1X_2$-0.7 $X_1X_3$-0.25 $X_2X_3$+1.8 $X_1X_2X_3$ |
| Best Treatment Combination | $X_1$=35 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=35 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=35 sec<br>$X_2$=380°F<br>$X_3$=60 psi<br>(1,-1,-1) |
| Estimated Max. Value | 19.63 | 29.70 | 20.40 |
| Target Value | 19.70 | 29.80 | 20.50 |
| Difference | 0.07 | 0.10 | 0.10 |

Based on Table 6g, it is shown that the dominant effect on the print contrast of the cotton fabric differs for the three colors observed. (As stated earlier, the print contrast of the cyan ink was not taken into consideration due to the not normal (negative) measurements taken.) For the print contrast of M, the dominant effect is $X_2X_3$, which is the interaction between the temperature ($X_2$) and the pressure ($X_3$). For the print contrast of Y, the dominant effect is $X_2$, which is the temperature of the heat transfer press. For

the print contrast of K, the dominant effect is $X_1X_2X_3$, which is the interaction between all three factors - the dwell time ($X_1$), the temperature ($X_2$), and the pressure ($X_3$). Table 6g also shows that the best treatment combination for the highest print contrast of the magenta and yellow inks for the cotton fabric is 35 seconds for the time, 400°F for the temperature, and 100 psi for the pressure (1,1,1). For the black ink, the best treatment combination is 35 seconds, 380°F, and 60 psi (1,-1,-1). Overall, a time of 35 seconds will yield the highest print contrast for all three colors. Since the dominant effects and the best treatment combinations are different, it proves that the print contrast for the blend fabric is not consistent.

## Equation Testing

The equations obtained from the regression analyses of the data were then tested to see how accurate they were. Table 7a shows the equations that were chosen for the testing and the best treatment combination for each equation. Table 7b shows the averages of the six sample measurements for each equation as well as the target value and the calculated difference between the two used to see how accurate the equations were.

Table 7a: *Equations & Best Treatment Combinations Used for Testing Equations*

| | Blend | | Polyester | | Cotton | |
|---|---|---|---|---|---|---|
| | Density of M | Density of K | Color Gamut | PC of C | Density of C | PC of Y |
| Prediction Equation (Y) | $1.450+0.00325 X_1+0.00625 X_2+0.02325 X_3-0.01125 X_1X_2-0.00425 X_1X_3+0.00375 X_2X_3+0.01125 X_1X_2X_3$ | $1.463+0.00275 X_1+0.00325 X_2+0.00475 X_3-0.00725 X_1X_2-0.00575 X_1X_3+0.00875 X_2X_3+0.00425 X_1X_2X_3$ | $291021.6+18304.3 X_1+8775.83 X_2+6586.73 X_3-1951.08 X_1X_2-1872.58 X_1X_3+1609.18 X_2X_3-1458.33 X_1X_2X_3$ | $12.725+0.825 X_1+1.325 X_2+0.925 X_3+0.225 X_1X_2+0.425 X_1X_2X_3$ | $1.149-0.00425 X_1+0.00825 X_2+0.03575 X_3+0.00225 X_1X_2+0.00475 X_1X_3+0.00525 X_2X_3+0.00325 X_1X_2X_3$ | $24.9+1.2 X_1+1.8 X_2+0.5 X_3+1.0 X_1X_2+1.2 X_1X_3-0.9 X_1X_2X_3$ |
| Best Treatment Combination | $X_1$=25 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(-1,1,1) | $X_1$=25 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(-1,1,1) | $X_1$=40 sec<br>$X_2$=420°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=40 sec<br>$X_2$=420°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=35 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(1,1,1) | $X_1$=35 sec<br>$X_2$=400°F<br>$X_3$=100 psi<br>(1,1,1) |

Table 7b: *Average Measurements Compared to Target Values Found During Equation Testing*

| | Blend | | Polyester | | Cotton | |
|---|---|---|---|---|---|---|
| | Density of M | Density of K | Color Gamut | PC of C | Density of C | PC of Y |
| Average of Measurements | 1.38 | 1.33 | 323145.50 | 16.17 | 1.31 | 35.17 |
| Target Value | 1.50 | 1.50 | 321050.00 | 16.60 | 1.30 | 29.80 |
| Difference | 0.12 | 0.18 | 2095.50 | 0.43 | 0.01 | 5.37 |

The testing of the equations showed that some were fairly accurate while others are a little off. The average measurements of the color gamut for the polyester as well as the density of C and print contrast of Y actually came out higher than the target value. All of the $R^2$ values for these equations fell between 0.91 and 0.99 which shows that there is some room for variation in the equations.

Visual Assessment Analysis

Tables 8a, 8b, and 8c show the results from the survey given to random subjects. The subjects were asked to rank the images from 1 to 8 with 1 being the best quality and 8 being the worst quality. The points were then added up and the images were ranked from best to worst overall based on the total amount of points received. The tables also show what the combination was for each of the images (this information was not given to the subjects).

Table 8a: *Survey Results for Blend Fabric*

| Survey Results (Blend) | | | |
|---|---|---|---|
| Rank | Combination | Image | Total Points |
| 1 | (-1,1,-1) | Image F | 58 |
| 2 | (-1,-1,-1) | Image H | 85 |
| 3 | (-1,-1,1) | Image E | 112 |
| 4 | (-1,1,1) | Image B | 118 |
| 5 | (1,-1,1) | Image G | 129 |
| 6 | (1,1,-1) | Image C | 141 |
| 7 | (1,1,1) | Image D | 149 |
| 8 | (1,-1,-1) | Image A | 180 |

Table 8b: *Survey Results for Polyester Fabric*

| Survey Results (Polyester) | | | |
|---|---|---|---|
| Rank | Combination | Image | Total Points |
| 1 | (1,1,1) | Image G | 59 |
| 2 | (-1,1,1) | Image A | 80 |
| 3 | (1,-1,1) | Image B | 83 |
| 4 | (-1,1,-1) | Image H | 98 |
| 5 | (1,1,-1) | Image E | 120 |
| 6 | (-1,-1,1) | Image D | 140 |
| 7 | (1,-1,-1) | Image F | 185 |
| 8 | (-1,-1,-1) | Image C | 207 |

Table 8c: *Survey Results for Cotton Fabric*

| Survey Results (Cotton) | | | |
|---|---|---|---|
| Rank | Combination | Image | Total Points |
| 1 | (-1,-1,-1) | Image A | 71 |
| 2 | (-1,-1,1) | Image C | 93 |
| 3,4 | (1,1,-1) | Image F | 103 |
| 3,4 | (1,1,1) | Image G | 103 |
| 5 | (-1,1,1) | Image E | 145 |
| 6 | (1,-1,1) | Image B | 149 |
| 7,8 | (1,1,-1) | Image D | 154 |
| 7,8 | (-1,1,-1) | Image H | 154 |

Table 8a shows that for the blend fabric, Image F (-1,1,-1) was found to be the best in quality because it had the lowest amount of total points and Image A (1,-1,-1) was found to be the worst in quality because it had the most total points. The results found from the measurements taken and analyses run in the experiment showed that the blend fabric was not very consistent in which combination was the best overall because many of the attributes had different best treatment combinations. The largest number of attributes was found to use the treatment combination of -1,1,1 which was ranked number 4 in the survey results. Results from the survey varied drastically for the blend fabric and it was hard to tell major differences in the visual assessment. This proves that it is not very consistent and there can be a larger range in the independent variable settings for the heat transfer press and visually, the product will look practically the same.

Table 8b shows that for the polyester fabric, Image G (1,1,1) was found to be the best in quality because it had the lowest amount of total points and Image C (-1,-1,-1) was found to be the worst in quality because it had the most total points. The results found from the measurements taken and analyses run in the experiment showed that the

best treatment combination for all but one of the attributes was 1,1,1 which was also shown in the survey results. This showed that the polyester fabric was very consistent and when the independent variables are set at different treatment combinations, the difference is obvious to the naked eye.

Table 8c shows that for the cotton fabric, Image A (-1,-1,-1) was found to be the best in quality because it had the lowest amount of total points and Image H (-1,1,-1) was found to be the worst in quality because it had the most total points. The results found from the measurements taken and analyses run in the experiment showed that the best treatment combination overall for the cotton fabric was more obvious than the blend fabric, but not quite as obvious as the polyester fabric. Majority of the attributes showed that 1,1,1 was the best combination for the cotton fabric, but the survey ranked that combination as number 3 (tied with 1,1,-1). Like the blend fabric, results from the survey varied drastically for the cotton fabric and it was hard to tell major differences in the visual assessment. This proves that it also is not very consistent and there can be a larger range in the independent variable settings for the heat transfer press and visually, the product will look practically the same. The inconsistencies in results of the visual assessments could be because of the lack of experience of the subjects and their not knowing exactly what to look for in the images.

# Chapter 5

## Conclusion

Tables 6a through 6g show the best treatment combinations for each of the different attributes for each fabric type. Overall, the best combination for the blend and cotton fabrics was hard to figure out based on the wide variety in best treatment combinations for each attribute. For the blend fabric, the best combination would probably have to be 25 seconds, 400°F, and 100 psi (-1,1,1) because more attributes found this combination to be the best combination possible. For the cotton fabric, the best treatment combination was a little more obvious but still not very consistent. The majority of the attributes found the combination of 35 seconds, 400°F, and 100 psi (1,1,1) to be the best. Finally, the polyester was proven to be the best fabric for this test. All but one of the attributes proved that the combination of 40 seconds, 420°F, and 100 psi (1,1,1) was the best combination possible in order to yield the maximum color gamut, densities, and print contrasts. The polyester was more consistent throughout the entire experiment and the survey results even agreed with the results from the experiment. This is probably due to the fact that dye sublimation inks are specifically designed for polyester materials. The i-Trans heat transfer paper is fairly new and may be the cause of the inconsistencies in the blend and cotton data.

Like the best treatment combinations, the dominant effects were not totally consistent either. Overall, for the blend fabric, the most dominant effect would have to have been the pressure ($X_3$) because more attributes had the pressure as the greatest percentage contributed than any other main effect of an independent variable or interaction of multiple independent variables. For the cotton fabric, the most dominant effect would have to have also been the pressure ($X_3$) based on the ANOVA tables.

Finally, for the polyester fabric, the most dominant effect was the dwell time ($X_1$). As with most other data collected in the experiment, the polyester fabric was more consistent than the blend and cotton fabrics in this area as well.

The visual assessment portion of this experiment was done to see whether random subjects could tell a difference in the images printed using different combinations of the variables when heat transferring them. These results in no way affect the results found from the experiment, but were interesting to look at. It was obvious that the blend and cotton samples were harder to rank than the polyester fabrics based on the results. The numbers varied more for the blend and cotton proving that those fabrics have a greater range for the variables because the differences cannot be easily noticed by the naked eye. The polyester provides a better color match when dealing with heat transfer printing. For future research, it would be beneficial to do a more reliable survey in order to see the real differences that can be observed by the naked eye. In order to be more reliable, either experts in the field could be chosen or the subjects could receive some type of training to help them know what to look for in the images. The phrase "best in quality" could have been interpreted differently by the subjects, so it would be better to get all of the subjects prepared to judge the same qualities in order to get better results.

Since the polyester fabric seemed to get better results for this experiment, for future research, it would be wise to do more with the cotton and blend to figure out why those were not as consistent. The i-Trans paper may have been the cause of these inconsistencies, so future research could be done to improve the paper or try to find a better way to heat transfer print onto cotton and blend fabrics. Also, for this experiment common settings for the fabrics were used, but maybe there are other settings that would

be better in order to yield better color gamut, densities, and print contrasts. (Maybe the highs should be higher; maybe the highs should be lower; maybe the lows should be higher; maybe the lows should be lower.) Future research could be done to find the best combinations to use for these types of fabric since there is not much heat transfer research done with these. Also for future research, it would be beneficial to look into the print contrast of C for the 100% cotton fabric more. The data measured for this attribute came out not normal (negative values), so tests could be done to see why these numbers came out negative and figure out what (if anything) could be changed to yield normal data.

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# Appendix A (Survey)

**Directions**: In this survey, you will evaluate a number of printed samples. Your task is to critique these printed samples on the merit of the appearance and impact of the photographic images.

**[Polyester Fabrics]**
Please rank the following images by which look the most appealing and best quality to you. (1 for most appealing; 8 for least appealing)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Image A | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image B | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image C | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image D | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image E | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image F | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image G | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image H | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |

**[50/50 Blend Fabrics]**
Please rank the following images by which look the most appealing and best quality to you. (1 for most appealing; 8 for least appealing)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Image A | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image B | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image C | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image D | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image E | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image F | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image G | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image H | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |

**[100% Cotton Fabrics]**
Please rank the following images by which look the most appealing and best quality to you. (1 for most appealing; 8 for least appealing)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Image A | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image B | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image C | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image D | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image E | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image F | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image G | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |
| Image H | ☐ 1 | ☐ 2 | ☐ 3 | ☐ 4 | ☐ 5 | ☐ 6 | ☐ 7 | ☐ 8 |

# Appendix B (Full ANOVA Tables)

## ANOVA Tables for 50/50 Blend

| Color Gamut (Blend) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 4176390.6 | 1 | 4176390.6 | 72.329 | 0.000 | 0.08% |
| Temperature | 156835800.6 | 1 | 156835800.6 | 2716.178 | 0.000 | 3.06% |
| Pressure | 4718648340.0 | 1 | 4718648340.0 | 81720.419 | 0.000 | 91.92% |
| AB | 47151951.0 | 1 | 47151951.0 | 816.606 | 0.000 | 0.92% |
| AC | 236083.2 | 1 | 236083.2 | 4.089 | 0.052 | 0.00% |
| BC | 105297005.0 | 1 | 105297005.0 | 1823.598 | 0.000 | 2.05% |
| ABC | 99467698.2 | 1 | 99467698.2 | 1722.642 | 0.000 | 1.94% |
| Error | 1847723.600 | 32 | 57741.363 | | | 0.04% |
| Total | 5133660992.375 | 39 | | | | |

| Density of C (Blend) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 0.0065 | 1 | 0.0065 | 130.050 | 0.000 | 13.24% |
| Temperature | 0.0093 | 1 | 0.0093 | 186.050 | 0.000 | 18.95% |
| Pressure | 0.0189 | 1 | 0.0189 | 378.450 | 0.000 | 38.54% |
| AB | 0.0112 | 1 | 0.0112 | 224.450 | 0.000 | 22.86% |
| AC | 0.0013 | 1 | 0.0013 | 26.450 | 0.000 | 2.69% |
| BC | 0.0002 | 1 | 0.0002 | 4.050 | 0.053 | 0.41% |
| ABC | 0.0000 | 1 | 0.0000 | 0.450 | 0.507 | 0.05% |
| Error | 0.002 | 32 | 0.000 | | | 3.26% |
| Total | 0.049 | 39 | | | | |

| Density of M (Blend) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 0.0004 | 1 | 0.0004 | 12.519 | 0.001 | 1.17% |
| Temperature | 0.0016 | 1 | 0.0016 | 46.296 | 0.000 | 4.33% |
| Pressure | 0.0216 | 1 | 0.0216 | 640.667 | 0.000 | 59.90% |
| AB | 0.0051 | 1 | 0.0051 | 150.000 | 0.000 | 14.02% |
| AC | 0.0007 | 1 | 0.0007 | 21.407 | 0.000 | 2.00% |
| BC | 0.0006 | 1 | 0.0006 | 16.667 | 0.000 | 1.56% |
| ABC | 0.0051 | 1 | 0.0051 | 150.000 | 0.000 | 14.02% |
| Error | 0.001 | 32 | 0.000 | | | 2.99% |
| Total | 0.036 | 39 | | | | |

| Density of Y (Blend) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 0.0044 | 1 | 0.0044 | 103.765 | 0.000 | 26.39% |
| Temperature | 0.0012 | 1 | 0.0012 | 28.471 | 0.000 | 7.24% |
| Pressure | 0.0084 | 1 | 0.0084 | 197.882 | 0.000 | 50.33% |
| AB | 0.0005 | 1 | 0.0005 | 11.529 | 0.002 | 2.93% |
| AC | 0.0001 | 1 | 0.0001 | 2.118 | 0.155 | 0.54% |
| BC | 0.0002 | 1 | 0.0002 | 5.882 | 0.021 | 1.50% |
| ABC | 0.0005 | 1 | 0.0005 | 11.529 | 0.002 | 2.93% |
| Error | 0.001 | 32 | 0.000 | | | 8.14% |
| Total | 0.017 | 39 | | | | |

| Density of K (Blend) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 0.0003 | 1 | 0.0003 | 11.524 | 0.002 | 3.13% |
| Temperature | 0.0004 | 1 | 0.0004 | 16.095 | 0.000 | 4.37% |
| Pressure | 0.0009 | 1 | 0.0009 | 34.381 | 0.000 | 9.33% |
| AB | 0.0021 | 1 | 0.0021 | 80.095 | 0.000 | 21.73% |
| AC | 0.0013 | 1 | 0.0013 | 50.381 | 0.000 | 13.67% |
| BC | 0.0031 | 1 | 0.0031 | 116.667 | 0.000 | 31.65% |
| ABC | 0.0007 | 1 | 0.0007 | 27.524 | 0.000 | 7.47% |
| Error | 0.001 | 32 | 0.000 | | | 8.68% |
| Total | 0.010 | 39 | | | | |

| PC of C (Blend) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 15.6250 | 1 | 15.6250 | 18.382 | 0.000 | 5.39% |
| Temperature | 42.0250 | 1 | 42.0250 | 49.441 | 0.000 | 14.49% |
| Pressure | 156.0250 | 1 | 156.0250 | 183.559 | 0.000 | 53.81% |
| AB | 27.2250 | 1 | 27.2250 | 32.029 | 0.000 | 9.39% |
| AC | 15.6250 | 1 | 15.6250 | 18.382 | 0.000 | 5.39% |
| BC | 2.0250 | 1 | 2.0250 | 2.382 | 0.133 | 0.70% |
| ABC | 4.2250 | 1 | 4.2250 | 4.971 | 0.033 | 1.46% |
| Error | 27.200 | 32 | 0.850 | | | 9.38% |
| Total | 289.975 | 39 | | | | |

| PC of M (Blend) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 4.9000 | 1 | 4.9000 | 10.316 | 0.003 | 10.75% |
| Temperature | 0.1000 | 1 | 0.1000 | 0.211 | 0.649 | 0.22% |
| Pressure | 0.9000 | 1 | 0.9000 | 1.895 | 0.178 | 1.97% |
| AB | 0.4000 | 1 | 0.4000 | 0.842 | 0.366 | 0.88% |
| AC | 1.6000 | 1 | 1.6000 | 3.368 | 0.076 | 3.51% |
| BC | 14.4000 | 1 | 14.4000 | 30.316 | 0.000 | 31.58% |
| ABC | 8.1000 | 1 | 8.1000 | 17.053 | 0.000 | 17.76% |
| Error | 15.200 | 32 | 0.475 | | | 33.33% |
| Total | 45.600 | 39 | | | | |

| PC of Y (Blend) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 34.2250 | 1 | 34.2250 | 42.123 | 0.000 | 27.17% |
| Temperature | 4.2250 | 1 | 4.2250 | 5.200 | 0.029 | 3.35% |
| Pressure | 13.2250 | 1 | 13.2250 | 16.277 | 0.000 | 10.50% |
| AB | 15.6250 | 1 | 15.6250 | 19.231 | 0.000 | 12.40% |
| AC | 11.0250 | 1 | 11.0250 | 13.569 | 0.001 | 8.75% |
| BC | 0.6250 | 1 | 0.6250 | 0.769 | 0.387 | 0.50% |
| ABC | 21.0250 | 1 | 21.0250 | 25.877 | 0.000 | 16.69% |
| Error | 26.000 | 32 | 0.813 | | | 20.64% |
| Total | 125.975 | 39 | | | | |

| PC of K (Blend) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 0.1000 | 1 | 0.1000 | 0.190 | 0.665 | 0.05% |
| Temperature | 16.9000 | 1 | 16.9000 | 32.190 | 0.000 | 9.03% |
| Pressure | 44.1000 | 1 | 44.1000 | 84.000 | 0.000 | 23.57% |
| AB | 96.1000 | 1 | 96.1000 | 183.048 | 0.000 | 51.36% |
| AC | 0.9000 | 1 | 0.9000 | 1.714 | 0.200 | 0.48% |
| BC | 0.1000 | 1 | 0.1000 | 0.190 | 0.665 | 0.05% |
| ABC | 12.1000 | 1 | 12.1000 | 23.048 | 0.000 | 6.47% |
| Error | 16.800 | 32 | 0.525 | | | 8.98% |
| Total | 187.100 | 39 | | | | |

## ANOVA Tables for 100% Polyester

| Color Gamut (Polyester) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 13401859331.0 | 1 | 13401859331.0 | 1358.904 | 0.000 | 70.48% |
| Temperature | 3080604177.2 | 1 | 3080604177.2 | 312.363 | 0.000 | 16.20% |
| Pressure | 1735397849.0 | 1 | 1735397849.0 | 175.964 | 0.000 | 9.13% |
| AB | 152267746.2 | 1 | 152267746.2 | 15.439 | 0.000 | 0.80% |
| AC | 140261485.2 | 1 | 140261485.2 | 14.222 | 0.001 | 0.74% |
| BC | 103577767.2 | 1 | 103577767.2 | 10.502 | 0.003 | 0.54% |
| ABC | 85068472.2 | 1 | 85068472.2 | 8.626 | 0.006 | 0.45% |
| Error | 315592171.600 | 32 | 9862255.363 | | | 1.66% |
| Total | 19014628999.775 | 39 | | | | |

| Density of C (Polyester) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 0.0308 | 1 | 0.0308 | 880.071 | 0.000 | 60.35% |
| Temperature | 0.0126 | 1 | 0.0126 | 360.071 | 0.000 | 24.69% |
| Pressure | 0.0038 | 1 | 0.0038 | 108.643 | 0.000 | 7.45% |
| AB | 0.0006 | 1 | 0.0006 | 16.071 | 0.000 | 1.10% |
| AC | 0.0006 | 1 | 0.0006 | 16.071 | 0.000 | 1.10% |
| BC | 0.0016 | 1 | 0.0016 | 44.643 | 0.000 | 3.06% |
| ABC | 0.0000 | 1 | 0.0000 | 0.643 | 0.429 | 0.04% |
| Error | 0.001 | 32 | 0.000 | | | 2.19% |
| Total | 0.051 | 39 | | | | |

| Density of M (Polyester) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 0.1323 | 1 | 0.1323 | 4809.091 | 0.000 | 59.79% |
| Temperature | 0.0504 | 1 | 0.0504 | 1833.091 | 0.000 | 22.79% |
| Pressure | 0.0281 | 1 | 0.0281 | 1021.455 | 0.000 | 12.70% |
| AB | 0.0017 | 1 | 0.0017 | 61.455 | 0.000 | 0.76% |
| AC | 0.0008 | 1 | 0.0008 | 29.455 | 0.000 | 0.37% |
| BC | 0.0062 | 1 | 0.0062 | 227.273 | 0.000 | 2.83% |
| ABC | 0.0008 | 1 | 0.0008 | 29.455 | 0.000 | 0.37% |
| Error | 0.001 | 32 | 0.000 | | | 0.40% |
| Total | 0.221 | 39 | | | | |

| Density of Y (Polyester) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 0.0416 | 1 | 0.0416 | 1664.100 | 0.000 | 59.54% |
| Temperature | 0.0172 | 1 | 0.0172 | 688.900 | 0.000 | 24.65% |
| Pressure | 0.0046 | 1 | 0.0046 | 184.900 | 0.000 | 6.62% |
| AB | 0.0051 | 1 | 0.0051 | 202.500 | 0.000 | 7.24% |
| AC | 0.0004 | 1 | 0.0004 | 16.900 | 0.000 | 0.60% |
| BC | 0.0000 | 1 | 0.0000 | 0.900 | 0.350 | 0.03% |
| ABC | 0.0001 | 1 | 0.0001 | 4.900 | 0.034 | 0.18% |
| Error | 0.001 | 32 | 0.000 | | | 1.14% |
| Total | 0.070 | 39 | | | | |

| Density of K (Polyester) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 0.0570 | 1 | 0.0570 | 2171.524 | 0.000 | 52.99% |
| Temperature | 0.0378 | 1 | 0.0378 | 1440.857 | 0.000 | 35.16% |
| Pressure | 0.0038 | 1 | 0.0038 | 144.857 | 0.000 | 3.53% |
| AB | 0.0003 | 1 | 0.0003 | 11.524 | 0.002 | 0.28% |
| AC | 0.0000 | 1 | 0.0000 | 0.857 | 0.361 | 0.02% |
| BC | 0.0051 | 1 | 0.0051 | 192.857 | 0.000 | 4.71% |
| ABC | 0.0027 | 1 | 0.0027 | 103.714 | 0.000 | 2.53% |
| Error | 0.001 | 32 | 0.000 | | | 0.78% |
| Total | 0.108 | 39 | | | | |

| PC of C (Polyester) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 27.2250 | 1 | 27.2250 | 83.769 | 0.000 | 17.91% |
| Temperature | 70.2250 | 1 | 70.2250 | 216.077 | 0.000 | 46.21% |
| Pressure | 34.2250 | 1 | 34.2250 | 105.308 | 0.000 | 22.52% |
| AB | 2.0250 | 1 | 2.0250 | 6.231 | 0.018 | 1.33% |
| AC | 0.6250 | 1 | 0.6250 | 1.923 | 0.175 | 0.41% |
| BC | 0.0250 | 1 | 0.0250 | 0.077 | 0.783 | 0.02% |
| ABC | 7.2250 | 1 | 7.2250 | 22.231 | 0.000 | 4.75% |
| Error | 10.400 | 32 | 0.325 | | | 6.84% |
| Total | 151.975 | 39 | | | | |

| PC of M (Polyester) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 115.6000 | 1 | 115.6000 | 355.692 | 0.000 | 42.75% |
| Temperature | 44.1000 | 1 | 44.1000 | 135.692 | 0.000 | 16.31% |
| Pressure | 62.5000 | 1 | 62.5000 | 192.308 | 0.000 | 23.11% |
| AB | 12.1000 | 1 | 12.1000 | 37.231 | 0.000 | 4.47% |
| AC | 4.9000 | 1 | 4.9000 | 15.077 | 0.000 | 1.81% |
| BC | 6.4000 | 1 | 6.4000 | 19.692 | 0.000 | 2.37% |
| ABC | 14.4000 | 1 | 14.4000 | 44.308 | 0.000 | 5.33% |
| Error | 10.400 | 32 | 0.325 | | | 3.85% |
| Total | 270.400 | 39 | | | | |

| PC of Y (Polyester) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 168.1000 | 1 | 168.1000 | 328.000 | 0.000 | 39.13% |
| Temperature | 176.4000 | 1 | 176.4000 | 344.195 | 0.000 | 41.06% |
| Pressure | 22.5000 | 1 | 22.5000 | 43.902 | 0.000 | 5.24% |
| AB | 36.1000 | 1 | 36.1000 | 70.439 | 0.000 | 8.40% |
| AC | 1.6000 | 1 | 1.6000 | 3.122 | 0.087 | 0.37% |
| BC | 8.1000 | 1 | 8.1000 | 15.805 | 0.000 | 1.89% |
| ABC | 0.4000 | 1 | 0.4000 | 0.780 | 0.384 | 0.09% |
| Error | 16.400 | 32 | 0.513 | | | 3.82% |
| Total | 429.600 | 39 | | | | |

| PC of K (Polyester) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 14.4000 | 1 | 14.4000 | 57.600 | 0.000 | 33.10% |
| Temperature | 0.9000 | 1 | 0.9000 | 3.600 | 0.067 | 2.07% |
| Pressure | 0.4000 | 1 | 0.4000 | 1.600 | 0.215 | 0.92% |
| AB | 10.0000 | 1 | 10.0000 | 40.000 | 0.000 | 22.99% |
| AC | 0.9000 | 1 | 0.9000 | 3.600 | 0.067 | 2.07% |
| BC | 6.4000 | 1 | 6.4000 | 25.600 | 0.000 | 14.71% |
| ABC | 2.5000 | 1 | 2.5000 | 10.000 | 0.003 | 5.75% |
| Error | 8.000 | 32 | 0.250 | | | 18.39% |
| Total | 43.500 | 39 | | | | |

## ANOVA Tables for 100% Cotton

| Color Gamut (Cotton) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 330659500.9 | 1 | 330659500.9 | 3296.499 | 0.000 | 6.98% |
| Temperature | 157061616.1 | 1 | 157061616.1 | 1565.821 | 0.000 | 3.31% |
| Pressure | 4082056568.1 | 1 | 4082056568.1 | 40695.929 | 0.000 | 86.16% |
| AB | 334890.0 | 1 | 334890.0 | 3.339 | 0.077 | 0.01% |
| AC | 92124390.4 | 1 | 92124390.4 | 918.431 | 0.000 | 1.94% |
| BC | 21100467.6 | 1 | 21100467.6 | 210.360 | 0.000 | 0.45% |
| ABC | 51424632.9 | 1 | 51424632.9 | 512.676 | 0.000 | 1.09% |
| Error | 3209800.400 | 32 | 100306.263 | | | 0.07% |
| Total | 4737971866.400 | 39 | | | | |

| Density of C (Cotton) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 0.0007 | 1 | 0.0007 | 27.524 | 0.000 | 1.24% |
| Temperature | 0.0027 | 1 | 0.0027 | 103.714 | 0.000 | 4.69% |
| Pressure | 0.0511 | 1 | 0.0511 | 1947.524 | 0.000 | 88.09% |
| AB | 0.0002 | 1 | 0.0002 | 7.714 | 0.009 | 0.35% |
| AC | 0.0009 | 1 | 0.0009 | 34.381 | 0.000 | 1.56% |
| BC | 0.0011 | 1 | 0.0011 | 42.000 | 0.000 | 1.90% |
| ABC | 0.0004 | 1 | 0.0004 | 16.095 | 0.000 | 0.73% |
| Error | 0.001 | 32 | 0.000 | | | 1.45% |
| Total | 0.058 | 39 | | | | |

| Density of M (Cotton) | | | | | | |
|---|---|---|---|---|---|---|
| Source | SS | df | MS | F | P | % Contrib |
| Time | 0.0004 | 1 | 0.0004 | 16.900 | 0.000 | 1.63% |
| Temperature | 0.0016 | 1 | 0.0016 | 62.500 | 0.000 | 6.01% |
| Pressure | 0.0189 | 1 | 0.0189 | 756.900 | 0.000 | 72.79% |
| AB | 0.0018 | 1 | 0.0018 | 72.900 | 0.000 | 7.01% |
| AC | 0.0013 | 1 | 0.0013 | 52.900 | 0.000 | 5.09% |
| BC | 0.0004 | 1 | 0.0004 | 16.900 | 0.000 | 1.63% |
| ABC | 0.0007 | 1 | 0.0007 | 28.900 | 0.000 | 2.78% |
| Error | 0.001 | 32 | 0.000 | | | 3.08% |
| Total | 0.026 | 39 | | | | |

| Density of Y (Cotton) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 0.0034 | 1 | 0.0034 | 136.900 | 0.000 | 18.97% |
| Temperature | 0.0027 | 1 | 0.0027 | 108.900 | 0.000 | 15.09% |
| Pressure | 0.0046 | 1 | 0.0046 | 184.900 | 0.000 | 25.63% |
| AB | 0.0004 | 1 | 0.0004 | 16.900 | 0.000 | 2.34% |
| AC | 0.0038 | 1 | 0.0038 | 152.100 | 0.000 | 21.08% |
| BC | 0.0018 | 1 | 0.0018 | 72.900 | 0.000 | 10.10% |
| ABC | 0.0004 | 1 | 0.0004 | 16.900 | 0.000 | 2.34% |
| Error | 0.001 | 32 | 0.000 | | | 4.44% |
| Total | 0.018 | 39 | | | | |

| Density of K (Cotton) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 0.0022 | 1 | 0.0022 | 94.737 | 0.000 | 5.38% |
| Temperature | 0.0073 | 1 | 0.0073 | 306.947 | 0.000 | 17.42% |
| Pressure | 0.0203 | 1 | 0.0203 | 852.632 | 0.000 | 48.40% |
| AB | 0.0032 | 1 | 0.0032 | 136.421 | 0.000 | 7.74% |
| AC | 0.0004 | 1 | 0.0004 | 15.158 | 0.000 | 0.86% |
| BC | 0.0014 | 1 | 0.0014 | 60.632 | 0.000 | 3.44% |
| ABC | 0.0062 | 1 | 0.0062 | 263.158 | 0.000 | 14.94% |
| Error | 0.001 | 32 | 0.000 | | | 1.82% |
| Total | 0.042 | 39 | | | | |

| PC of M (Cotton) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 21.0250 | 1 | 21.0250 | 80.095 | 0.000 | 23.68% |
| Temperature | 9.0250 | 1 | 9.0250 | 34.381 | 0.000 | 10.17% |
| Pressure | 4.2250 | 1 | 4.2250 | 16.095 | 0.000 | 4.76% |
| AB | 5.6250 | 1 | 5.6250 | 21.429 | 0.000 | 6.34% |
| AC | 0.0250 | 1 | 0.0250 | 0.095 | 0.760 | 0.03% |
| BC | 27.2250 | 1 | 27.2250 | 103.714 | 0.000 | 30.67% |
| ABC | 13.2250 | 1 | 13.2250 | 50.381 | 0.000 | 14.90% |
| Error | 8.400 | 32 | 0.263 | | | 9.46% |
| Total | 88.775 | 39 | | | | |

| PC of Y (Cotton) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 57.6000 | 1 | 57.6000 | 230.400 | 0.000 | 17.16% |
| Temperature | 129.6000 | 1 | 129.6000 | 518.400 | 0.000 | 38.62% |
| Pressure | 10.0000 | 1 | 10.0000 | 40.000 | 0.000 | 2.98% |
| AB | 40.0000 | 1 | 40.0000 | 160.000 | 0.000 | 11.92% |
| AC | 57.6000 | 1 | 57.6000 | 230.400 | 0.000 | 17.16% |
| BC | 0.4000 | 1 | 0.4000 | 1.600 | 0.215 | 0.12% |
| ABC | 32.4000 | 1 | 32.4000 | 129.600 | 0.000 | 9.65% |
| Error | 8.000 | 32 | 0.250 | | | 2.38% |
| Total | 335.600 | 39 | | | | |

| PC of K (Cotton) | | | | | | |
|---|---|---|---|---|---|---|
| **Source** | **SS** | **df** | **MS** | **F** | **P** | **% Contrib** |
| Time | 16.9000 | 1 | 16.9000 | 58.783 | 0.000 | 6.34% |
| Temperature | 3.6000 | 1 | 3.6000 | 12.522 | 0.001 | 1.35% |
| Pressure | 22.5000 | 1 | 22.5000 | 78.261 | 0.000 | 8.45% |
| AB | 62.5000 | 1 | 62.5000 | 217.391 | 0.000 | 23.46% |
| AC | 19.6000 | 1 | 19.6000 | 68.174 | 0.000 | 7.36% |
| BC | 2.5000 | 1 | 2.5000 | 8.696 | 0.006 | 0.94% |
| ABC | 129.6000 | 1 | 129.6000 | 450.783 | 0.000 | 48.65% |
| Error | 9.200 | 32 | 0.288 | | | 3.45% |
| Total | 266.400 | 39 | | | | |