4-1-1987

The effect of solid ink density on shifts in hue in gray component replacement

Hans P. Kellogg

Certificate of Approval -- Master's Thesis

School of Printing
Rochester Institute of Technology
Rochester, New York

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's Thesis of

Hans P. Kellogg
Hans P. Kellogg

With a major in Printing Technology
has been approved by the Thesis Committee as
satisfactory for the thesis requirement for the
Master of Science degree at the convocation of

May 1987
date

Thesis Committee: Joseph L. Noga
Thesis Advisor

Joseph L. Noga
Graduate Program Coordinator

Miles Southworth
Director of Designate

THE EFFECT OF SOLID INK DENSITY
ON SHIFTS IN HUE
IN GRAY COMPONENT REPLACEMENT

THE EFFECT OF SOLID INK DENSITY
ON SHIFTS IN HUE
IN GRAY COMPONENT REPLACEMENT

by

Hans P. Kellogg

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing Management and Science in the College of Graphic Arts and Photography of the Rochester Institute of Technology

April, 1987

Thesis Advisor: Professor Joseph Noga

This thesis is dedicated to my dad, Joseph J. Blackmore, who passed away March 3, 1985. His commitment and support to education inspired me to pursue my own. His presence is greatly missed.

ACKNOWLEDGEMENTS

A note of thanks is given to the following people for their help in the completion of this thesis.

Franz Sigg, Research Associate at the Technical and Education Center for the Graphic Arts at Rochester Institute of Technology, Rochester, New York, was of assistance in the design of the press form used for this research. His comments and ideas are appreciated.

Dr. John Campbell, Assistant Professor of Biology, Northwest Community College, Powell, Wyoming, for his persistent work and assistance in the completion of the statistical work for this thesis.

Claude Dotson, Assistant Professor of Data Processing, Business, and Office Administration, Northwest Community College, Powell, Wyoming, was a helpful in the areas of editing and proofreading. His expertise is greatly appreciated.

Cheryl H. Kellogg, Instructor of Medical Laboratory Technology, Northwest Community College, Powell, Wyoming, receives a special thanks for her understanding. As the wife of a graduate student, she has struggled along with me throughout this process. I love her dearly.

TABLE OF CONTENTS

LISTS OF FIGURES

LIST OF TABLES

ABSTRACT

With advances in computer storage and electronic dot generation scanners a new color separation process has become possible. Although in theory the Gray Component Replacement (GCR) process has been possible since the early twenties, it has only recently been available through contemporary color separation methods.

GCR is the process by which the gray component of a particular color reproduction is removed from the reproduction and replaced with black ink. The gray component is defined as specific combinations of the least predominant color and the other remaining inks.

A printing form was designed to include three different color reproduction processes: the 100% GCR, 60% GCR, and normal chromatic. A standard color transparency used for color evaluation was included with a series of 24 color test patches. A colorimeter was used as the test instrument, and the color patches provided ease in measurement using the instrument.

The form was mounted on the lithographic press and the press

was run to match the proof. Once a color OK was obtained and samples obtained, ink densities of the other units were selectively varied to provide a shift in hue.

A colorimeter was used to obtain a value of Delta hue from the selected press sheets. Each standard color press sheet was measured and recorded as a standard with successive readings measured in terms of Delta hue. The color test patches were divided into groupings of neutral gray, hard to print, process/overprint, and all colors. Each Delta hue measurement was recorded and grouped into the specific categories.

The variations of the normal chromatic and the 100% GCR separations were compared, as well as the variations of the normal chromatic and the 60% GCR process. This is to say that the neutral gray color grouping compared the measurements of the 100% GCR to the measurements of the normal chromatic process. These same measurements were taken for each variation within each color grouping.

Delta hue readings for each of the color groupings was used to calculate a t-value and test the significance of the difference between the different processes. If there was indeed a difference between the different processes then a t-value of 1.65 would result.

A level of significance of .05 was obtained in all of the comparisons. The GCR does reduce shifts of hue on the lithographic press. This reduction in shifts of hue should relate to an increase use of the GCR process in the future.

Chapter 1

INTRODUCTION

The GCR Color Process

Advances in computer storage and electronic dot generating scanners have opened up new areas for the printing industry. Although the theory was conceived long ago, it is only now possible to produce the gray component replacement (GCR) process. It is uncertain whether GCR is the process that will become the major color separation method of the future, for as a whole, the printing industry is hesitant to embrace new technology before it has proven itself.

Claims for the GCR process include many advantages,[1] ranging from decreased ink consumption, increased color brightness, reduced trapping problems, to ease of control on the lithographic press. The disadvantages--such as retraining of color separators, dot etchers, platemakers, and press crews--seem insignificant when considering all the reputed

---

[1] Programmed and Complementary Color Reduction, Dr. Eggert Jung, Dr. -Ing. R. Hell Gmbh, Germany, Technical Association for the Graphic Arts, Proceedings of the Thirty-Sixth Annual Meeting (Boston Mass., 1984), p. 136

gains.[2] The problem of having GCR as a major color separation process in the printing industry today is presented with the following questions. Does the result of this process support these claims? Will this process take over 80% of the future color printing market?[3] Or is GCR's only claim the ability to provide special applications for selected areas of the printing market?

The commercial printing industry has been interested in answers to these questions but has found it difficult to take the time to conduct research. Much of the research and development has been conducted by the scanner manufacturers. It is not surprising that these manufacturers are interested in a process that allows them to offer unique advantages and increase equipment sales. Their work provides an important service, but there is also a need to pursue research from an unbiased position.

COLOR THEORY

To understand the advantages of the GCR printing process, an

---

[2] Ibid., p. 136

[3] "Investigation into the Application of Achromatic Synthesis to the Printing Industry," Dr. Abdel Ghany Saleh, <u>Technical Association for the Graphic Arts</u>, Proceedings of the Thirty-Sixth Annual Meeting (Boston Mass., 1984), p. 151

understanding of basic color theory is necessary. The small portion of the electromagnetic spectrum that produces visible light is composed of individual wavelengths of 380 to 750 nanometers. When combined, these wavelengths provide the visual sensation of white light.

Additive Color Theory

If white light were to pass through a prism and shine on a surface, the entire portion of the visual light spectrum would be broken into its many components. The red, green, and blue portions of light contribute the largest part of the light spectrum. These three major colors are considered

red + blue = magenta

red + green = yellow

blue + green = cyan

Figure 1. Colors resulting from mixing equal portions of the additive primaries

the primary colors of the additive color process, the production of colors by mixing colored lights. Addition of all three primary colors produces white light; equal portions of any two of the primaries produce a third color. (Figure 1.)

Subtractive Color Theory

The printing industry, however, uses the subtractive color process. Magenta, cyan, and yellow are the subtractive primaries used in the color inks. Each individual transparent ink acts as a filter to "subtract" a portion of white light. A yellow ink appears yellow because of the reflectance of red and green light from the substrate. As the white light strikes the surface, the blue portion of the light spectrum is absorbed. The remaining portions of visible light, red and green, reflect from the substrate to produce the yellow color. Combinations of any two of the subtractive primaries produce the colors that are the primary colors of the additive process. (Figure 2)

If blue, green, and red light are reflected from an object, the object's perceived color is white. If an object absorbs 100% of the three portions, then its perceived color would be black.

Observation of Color

Three components are necessary with any color observation:

the object observed, the light source, and the detector.[4]

cyan + yellow = green

magenta + yellow = red

cyan + magenta = blue

Figure 2. Colors resulting form overlap of equal portions of any two subtractive primaries.

When a red apple is illuminated by "white" light, the blue and green portions of the light spectrum are absorbed by the surface of the apple and the red is reflected. We perceive

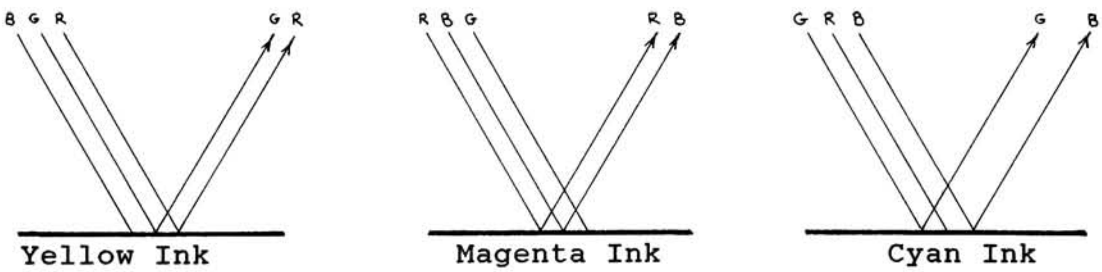

Figure 3. Reflectances of white light from yellow, magenta, and cyan Ink

the apple is red because red is the color of light that is reflected to the viewer.

A reproduction of an apple produced by the subtractive

---

[4] Fred W. Billmeyer, Jr., and Max Saltzman, Principles of Color Technology, (John Wiley and Sons, Inc., 1976), p. 4.

process uses magenta and yellow ink to produce the color red. Magenta absorbs the green portion of the spectrum, and the yellow absorbs the blue. The red portion is reflected back to the eye, and the color of the reproduction of the apple appears red in color. (Figure 3)

Reproduction Processes

A bar graph depicting the amount of ink used in a normal chromatic reproduction of an apple would indicate a small portion of cyan ink. This cyan ink would darken the hue or the color of the apple. An ink contributing the smallest amount to the hue of the reproduction will be considered the least predominant color (LPC). (Figure 4) With the 10% cyan determined to be the least predominant color, a combined portion of 10% cyan, 10% magenta, and 10% yellow could be considered a neutral gray or gray component.

In the GCR printing process this gray component is replaced with black ink. As in the normal chromatic process, the neutral gray is identified as the LPC combined with equal amounts of the other two color inks. Black is used to replace the gray component, and the hue of an object is thus determined by two of the remaining colored inks. The black ink acts only as a darkening factor to the hue of the reproduction.

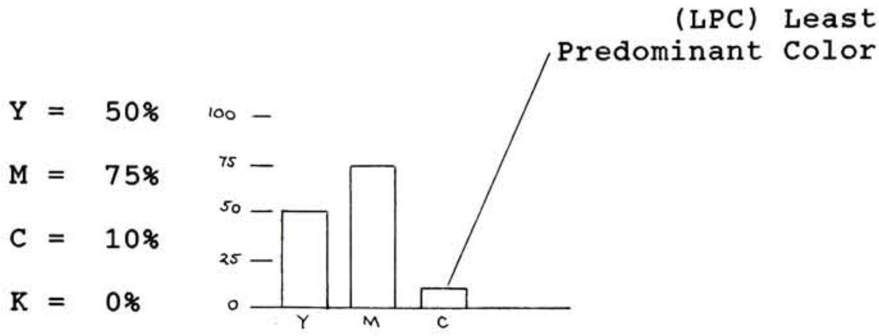

Figure 4. Differing amounts of yellow, magenta, and cyan ink required to reproduce a printed reproduction of a red apple.

Two primary methods have been explained to this point: normal chromatic reproduction and the GCR process. A third alternative is a combination of the two. In the previously explained GCR process, the LPC was completely removed and replaced with black. Expressed as percentages, this GCR process would be considered 100% GCR from a result of the complete removal of the LPC. The normal chromatic process, as previously stated, represents the absence of the removal of the LPC. For ease of explanation, the process will be considered 0% GCR. Any point between these extremes would entail partial reduction of the LPC. When the use of GCR reaches 100%, shadow areas of the reproduction are reproduced entirely by the black printer. Used by itself, the density of the black printer lacks the depth that is possible by printing the 3 process colors plus black. Singly and on coated stock, black ink is capable of dens-

ities of 1.80. On similar stock, combined process inks plus black can reach densities of 2.00.[5] If 100 % GCR is used, the shadows will lack the contrast that is currently possible with normal chromatic reproduction processes. Because of this lack of shadow density, limits have been recommended in the use of the amount of GCR in a reproduction.

To alleviate the lack of density present in the dark shadows, another control is used. When high percentages of GCR are used, under color addition (UCA) adds the LPC back to the reproduction. This addition differs from smaller percentages of GCR in that the UCA only affects the neutral areas. This effect is the complete opposite of the under color removal (UCR), which has been used for many years in the color separation trade. Where UCR removes color from the neutrals to alleviate density problems, UCA adds color to the neutrals to increase density.

Apparently, no advantages exist for the use of the GCR process in the pre-press area. The claims of reduced ink consumption, reduced trapping, increased color saturation, or reduced study picking relate to the press and finishing areas. This paper will focus on the reduction of shifts in

---

[5] Miles Southworth, <u>Color Separation Techniques</u>, 2nd ed., (Graphic Arts Publishing, Livonia, New York 1981), p. 26.

hue available to press operators.[6]

As stated earlier, wherever three transparent color inks overlap, the two predominant inks produce the hue of the color, and the third or LPC ink produces the graying or darkening factor of the color.[7] The LPC can be combined with equal amounts of the other inks to form an achromatic

Hue of the red apple	Gray component of the apple
65% MAGENTA	10% MAGENTA
40% YELLOW	10% YELLOW
0% CYAN	10% CYAN

Figure 5. Gray component of a reproduction of a red apple

or gray component. In a color reproduction of a red apple, if the color red was composed of 75% magenta, 50% yellow, and 10% cyan, the cyan would be defined as the LPC. Further removal of the gray component would yield the results as in Figure 5:

This explanation considers the inks as if they were produced

---

6 Gunter Keppler, "PCR-Programmed Colour Removal, Klischograph 1982, (1982), Dr. -Ing. R. GmbH, Kiel, Germany, p. 22.

7 Jung, Technical Association of the Graphic Arts, Proceedings of the Thirty-Sixth Annual Meeting, p. 140.

from pure pigments, absorbing 1/3 and reflecting 2/3 of the visible spectrum.[8] (Figure 6) No allowance has been made for the natural contamination of the process printing inks. Real process inks produce slightly different results because of apparent contaminations.

cyan absorbs red, reflects blue and green

yellow absorbs blue, reflects green and red

magenta absorbs green, reflects red and blue

Figure 6. Absorption and reflectance of white light from the substrate using pure inks (taken from Kodak Publication, Basic Color for the Graphic Arts, Q-7)

Contaminations of Real Inks

The unavailability of pure inks requires the printing industry to use inks that react as if they contain unwanted contaminates. These contaminates produce added absorptions of other portions of the light spectrum. Cyan not only absorbs the red portion but also absorbs certain amounts of the green and blue portions. Magenta absorbs the green portion but produces unwanted absorption of the blue portion. The yellow ink is the most pure of the three, with

[8] Southworth, Color Separation Techniques, p. 12.

little if any unwanted absorption.[9] (Figure 7)

One criteria for quality color reproduction is the ability to reproduce a neutral gray color with the three process color inks. In theory, this should be possible with equal dot percentages of all three inks, i.e., 50% yellow, 50% magenta, and 50% cyan. In fact, slightly increased amounts

INK ABSORPTION

CYAN	MAGENTA	YELLOW
70% CYAN	60% MAGENTA	100% YELLOW
20% MAGENTA	30% YELLOW	(almost perfect)
10% YELLOW	10% CYAN	

Figure 7. Absorption and reflectance of white light by real Inks (taken from Kodak Publication, Basic Color for the Graphic Arts, Q-7)

of cyan should be used to produce the neutral gray effect due to the lack of color correction in the neutral areas of the reproduction. The removal of the gray component should include the proper gray balance for the particular ink set that is used. Gray balance and the unwanted absorptions of real inks can make the replacement of the gray component difficult to understand. In reality, the replacement

[9] Ibid, p. 31.

process does not define the gray component by a simple reduction of equal portions of the three process colors. An olive green color will display the possible complications that surround the GCR process.[10] A normal chromatic color reproduction of olive green should produce the results shown in Figure 8.

The theoretical GCR process replaces the gray component with black ink and reduces by 50% the amount of ink that determines the hue. (Figure 9)

In the actual GCR process, this 50% reduction would not occur. With the unwanted absorptions of the process colors and the need to reduce the magenta and yellow ink to achieve

Y = 100%

M = 50%

C = 60%

K = 0%

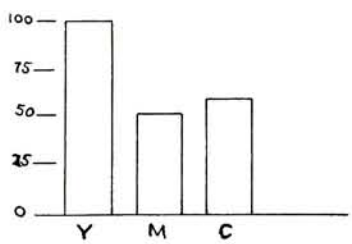

Figure 8. Percent dot area of yellow, magenta, cyan, and black ink in a normal chromatic reproduction of olive green (taken from Achromatic Synthesis, marketing information, Hell Graphics, Dr.-Ing. Rudolf Hell, Gmbh, Kiel, Germany, 1983)

---

[10] Saleh, Technical Association for the Graphic Arts, Proceedings of the Thirty-Sixth Annual Meeting, p. 151.

Y = 50%

M = 0%

C = 10%

K = 50%

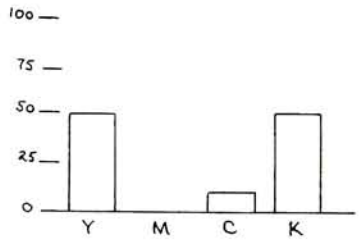

Figure 9. Expected GCR reproduction (taken from Achromatic Synthesis, marketing information, Hell Graphics, Dr.-Ing. Rudolf Hell, Gmbh, Kiel, Germany, 1983)

gray balance, the GCR reproduction would yield different results as in Figure 10.[11]

Kueppers, et al., claim GCR allows more variation in ink levels with reduced shifts in color on the lithographic offset press.[12] If the LPC has an increase or a decrease in solid ink density (the measurement of a solid ink film through a reflection densitometer), the color produced from the combinations of the three inks will not experience a shift in hue. This follows logically because an increase in the LPC would not affect an ink combination from which it had been removed. Adjustment of the solid ink density (SID) of the cyan would not change the particular hue.

The previous example of the red apple defines the gray component by a representation of a dotted line. This line

---

[11] Ibid, p. 140.

[12] Harald Kueppers, An Atlas for Color Mixing, p. 150, english language edition, (Barron's, Woodbury, New York, 1982)

Y = 95%

M = 15%

C = 0%

K = 65%

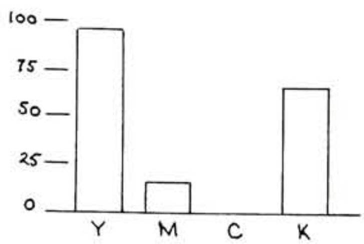

Figure 10. Actual GCR reproduction (taken from <u>Achromatic Synthesis</u>, marketing information, Hell Graphics, Dr.-Ing. Rudolf Hell, Gmbh, Kiel, Germany, 1983)

identifies the gray component as a combination of 10% of cyan, magenta, and yellow. The portion of the color that is above the dotted line identifies the hue of the color. (Figure 11.)

Y = 50%

M = 75%

C = 10%

K = 0%

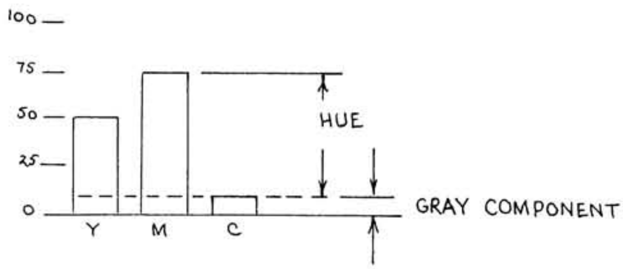

Figure 11. Division of the gray component from the hue in a normal chromatic color reproduction of red apples

Although the LPC may increase or decrease in SID, with the 100% GCR the hue will stay the same. A slight shift in hue will result from the 60% GCR due to the minimal amounts of LPC present in the reproduction. Hence, GCR theoretically

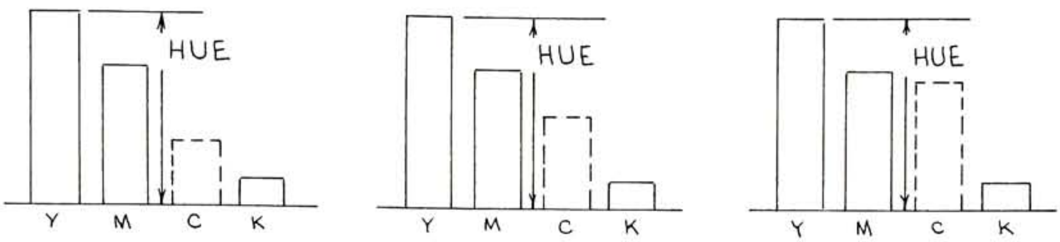

Figure 12. Shifts of hue during variation in SID of LPC in the GCR process

reduces the shifts of hue when compared to normal chromatic reproductions. (Figure 12)

The normal chromatic reproduction will experience a shift in hue with the increase or decrease of the LPC. (Figure 13)

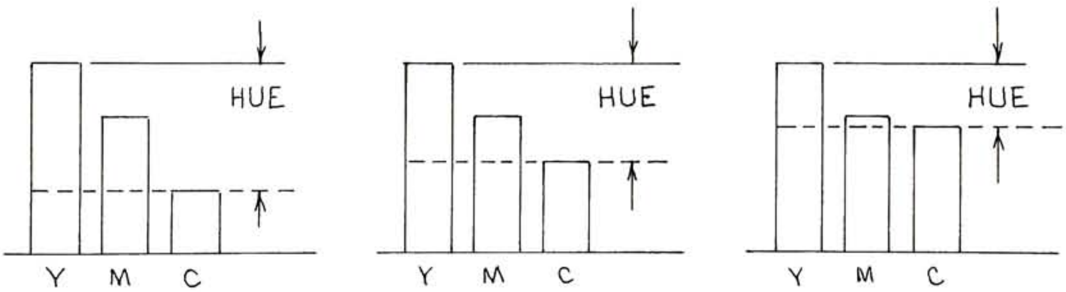

Figure 13. Shifts of hue during variations in SID of LPC in the chromatic process

Chapter 2

LITERATURE REVIEW

In Color Atlas, A Practical Guide for Color Mixing, Harald Kueppers credits Wilhelm Ostwald with the first accounts of GCR in 1921 in the German magazine Die Farbe [Color]. The process was first described in the United States in 1948. Arthur C. Hardy and F. L. Wurzburg presented a set of equations that would utilize a scanner to produce a set of separations that look "unlike those to which the art is accustomed."[1] Further, they explained "if a gray scale is included with the subject, it is not reproduced at all by the color plates but only by the black plate." To achieve this result requires the separation of the darkening area, or gray component, from the reproduction. Other papers written by Hardy and Wurzburg described the theoretical basis for such a "scanning machine."[2] Hardy and Wurzburg added that "only with the use of electronics could such complex color correction calculations be performed with

[1] A. C. Hardy and F. L. Wurzburg Jr., "Color Correction in Color Printing," Journal of the Optical Society of America, vol. 38, no. 4, April, 1948, p. 300.

[2] A. C. Hardy, F. L. Wurzburg Jr., "An Electronic Method for Solving Simultaneous Equations," Journal of the Optical Society of America, vol. 38, no. 4, April, 1948, p. 308.

sufficient speed to make such a theory feasible."[3] In the 1954 TAGA proceedings, Phil Tobias repeated the idea of a scanner machine and again discussed the question of reducing or replacing the gray component.[4] It was only a matter of time before the technology would make such a process feasible.

Harald Kueppers' Color Atlas presented some of the first examples of actual GCR processing.[5] Using screen tints to represent the properties of the GCR process, Kueppers produced a color guide for both the chromatic and achromatic color processes. Side by side, these charts showed the advantages of the GCR process. When Kueppers' book was published, his "new" color process could only be mechanically assembled. With recent advances in color separation, electronic scanners are now capable of this process. Increasingly, industry now considers GCR a possibility.

Corporate research and development departments have been persistent in pursuing the production of the GCR process. This increased interest has resulted in many recent publications. At the 1984 TAGA meeting, Dr. Eggert Jung of Dr.

---

[3] Ibid., p. 308.

[4] Philip E. Tobias, "A Color Correction Process," Edward Stern and Company, Inc., Technical Association for the Graphic Arts, 1954, p. 85.

[5] Kueppers, An Atlas for Color Mixing

-Ing. R. Hell Gmbh, Keil, Germany, explained the GCR processing of the Hell scanners manufactured by his firm.[6] Hell has two different versions available, programmed color removal (PCR) and the complementary color reduction (CCR). CCR is Hell's terminology for gray component replacement and is an option on many of their new scanners. PCR is the GCR process that uses digital transformation tables programmed into their Chromacom pagination system.[7]

Dr. Abdel Ghany Saleh presented a more general explanation of the achromatic synthesis at the 1984 TAGA meeting.[8] Dr. Abdel Ghany Saleh's diagrams have been used to explain the theory behind the GCR process in this research.

Mike Bruno, editor of Technology and Trends, helped introduce the concept of the GCR process in trade journals.[9] His article "Achromatics, Four-Color Printing that Isn't" in American Printer explained the concepts of this new color printing process to the general printing public. Bruno explained the advantages and reasoning underlying this

---

[6] Jung, Technical Association for the Graphic Arts, Proceedings of the Thirty-Sixth Annual Meeting, p. 136.

[7] Ibid., p. 136

[8] Saleh, Technical Association for the Graphic Arts, Proceedings of the Thirty-Sixth Annual Meeting, p. 157.

[9] Mike Bruno, Achromatics, Four Color Printing that isn't, American Printer vol. 194 (January 1985), p. 40-44

complicated and technologically advanced color system.

BACKGROUND

Advanced research in the GCR process first took place in Europe, where German researchers coined the term "unbunt-aufbau," a direct translation of which produces the word "achromatic" or "with-out color." Webster's New World Dictionary defines achromatic as "1. colorless 2. refracting white light without breaking it up into its component colors."[10] To use an optical term that describes the absence of color and apply it to a color reproduction process was inappropriate. Franz Sigg, researcher at the Technical and Education Center for the Graphic Arts at Rochester Institute of Technology, polled people in both education and industry for input to determine a new term. He derived "Gray Component Replacement," a more apt definition than achromatic for a process that removes the gray component of a color and replaces it with black.[11]

---

[10] Webster's New World Dictionary, 2nd ed., World Publishing Co., Inc., Cleveland, New York, p. 11.

[11] Franz Sigg, "On Second Though, Let's Call It Gray-Component Replacement" T+E Center Newsletter, Technical and Educational Center for the Graphic Arts, Rochester Institute of Technology, vol. 12, no. 6, (Sept/Oct 1984).

Statement of Purpose

If the GCR process does indeed reduce shifts in hue then the advantage of using this process should be promoted. Much of the waste in the lithographic press is a result of variations of color or shift of hue. The elimination of waste can be viewed as a direct reduction of costs.

HYPOTHESIS

If variations of SID are encountered, tendency for the press sheet to shift in hue will be reduced with the GCR process compared to the normal chromatic color process.

Chapter 3

METHODOLOGY

Testing the hypothesis required the design of a special printing form. Each of the three different color reproduction processes--normal chromatic, 60% GCR, and 100% GCR/50% UCA--were represented through the printing of a photograph and a series of 24 color patches. Each color patch was divided diagonally so that every square of color would provide sample segments depicting the 4 color, 3 color, and black used in the reproduction. This allowed a visual comparison of the gray component that was removed in each of the three, color printing processes. (Figure 14)

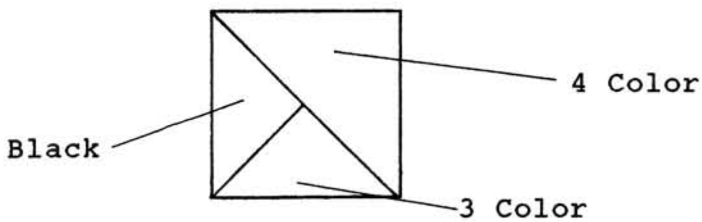

Figure 14. A example of the segmented color test patches depicting 4 color, 3 color, and black only.

The photographic examples provided three sets of separations to be used in the research. The normal chromatic reproduction-SWOP specifications (Specifications for Web Offset Publication) state the combined maximum printing dot should

not exceed 280%.[1] The other separations were the 60% GCR-0% UCA and 100% GCR-50% UCA. These were designated A, B, and C respectively and positioned from left to right near the tail edge of the form.

The SWOP standard is used in conjunction with publications printing to alleviate the excessive amounts of ink printing in one area of the press sheet. Reduction of the maximum printing dot was accomplished with the use of UCR, the reduction of the three process color inks with the replacement of black.[2] Only the neutral areas of the reproduction are reduced with the sole purpose of reducing inking problems associated with excessive ink coverage on the lithographic press. UCR has no significant visual effect on the reproduction.

The varied reproductions of the segmented color test patches were placed towards the lead edge of the press sheet for precise control on the lithographic press. Numbering allowed simple identification of the different processes and test patches. Thus, color patch B-18 represented a repro duction of the 18th color patch for the 60% GCR/0% UCA process.

---

[1] Miles Southworth, "New SWOP Publication," <u>The Quality Control Scanner</u>, vol. 1, no. 3, (1981), p. 2

[2] J, A. Yule, <u>Principles of Color Reproduction</u>, p. 282, (John Wiley and Sons, Inc.)

Variation in density control across the press cylinder required that the corresponding hues align around the cylinder. Hence, the color patches were divided into groups of corresponding hues. Under the photograph of the normal chromatic reproduction were the color patches A 1-8, B 1-8, and C 1-8. Similar groups of patches--A, B, and C 9-16 and A, B, and C 17-24--were placed under the photographs of the other two reproduction processes (60% GCR/0% UCA and 100% GCR/50% UCA). (Figure 15)

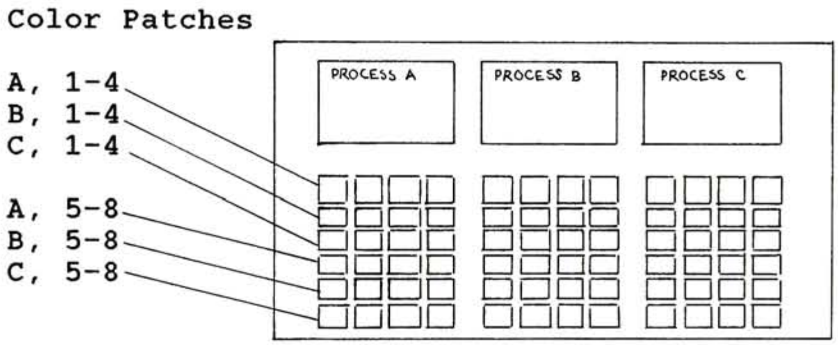

Figure 15. Layout of the thesis printing form

The transparency selected for reproduction was a standard 4 x 5 Ektachrome used by the Electronic Color Imaging Laboratory at Rochester Institute of Technology. A "standard" transparency is defined as suitable for color evaluation in the separation process. The transparency included fruit, vegetables, wood, and plants to represent memory colors and neutral grays. A McBeth Color Checker was also included in

the transparency. Each color reproduction process was scanned twice, once for the complete image of the transparency and again to include an enlarged area of the McBeth Color Checker. The area of the transparency that included the color checker produced the different "color patch" separations.

A RIT Color Control Strip was included with the separations, as was a RIT Symmetrical Test Target and a UGRA Plate Control Wedge. These devices provided a method of monitoring and controlling the different stages of production. The form including the test targets was assembled onto flats and exposed to plates, and the plates were mounted on the press. During the pressrun, the press controls were adjusted to have the printing form match the proof. Matching was done subjectively by visually comparing the photographic image of the press sheet and proof. When a match was accomplished, sample press sheets were gathered to provide a set of "standard" densities. These samples provided a base from which to judge the variation in hue on the lithographic press.

After the standard samples were gathered, the press crew selectively increased and then decreased the ink feed of the press. Each printing unit was varied individually for each of the four process color inks. Samples were collected in

bulk during each press adjustment, and the prescribed variations of SID were sorted at a later date. The increases and decreases in ink feed were adjusted until a shift in hue was visibly noticed. When this was accomplished, the press was returned to the standard density settings. The same sequence was followed for the each press unit. The collection of pressheets provided densities which varied from the standard by -.10, -.20, -.30 and +.10, +.20, +.30 units of density. The increases and decreases in intervals of density values of .10 were figured on the standard run itself. For example, the run was stabilized at +/-0.05 of the standard, and the samples were sorted at an average .10 intervals above and below that standard not to exceed +/-.30 density value.

The instrument that was used for testing the press sheets was a Hunter Lab Scan LS-12015 spectrocolorimeter. Use of this instrument was important because it closely matches the spectral sensitivity of the human eye. If shifts of hue are to be the subject of this paper, then the instrument chosen must be able to measure the variable in question. The Lab Scan has the ability to store a color measurement as a "standard," with the following readings measured as a "trial." Each color patch from the standard sheets was measured considering it the "standard" hue, with other colors measured in terms of change of hue, or more specif-

ically, Delta hue. Delta hue is defined as the change of hue as calculated by the Hunter Lab Scan colorimeter.

Color Groupings

For statistical testing the color patches in the McBeth Color Checker were grouped into four distinct categories that define particular problems or different variables that surround the color printing. These four color groups were neutral grays, process and overprint colors, hard to print colors, and all colors.

The neutral gray color was chosen because of the importance of gray balance. Gray balance is the ability to print a neutral gray color with the three process colors. This ability is extremely important in the control of high-quality color printing. If gray balance is obtained, it is expected that a balance of the other colors should also be maintained.

The process and overprint color patches include reproductions of the colors yellow, magenta, cyan, blue green, and red. Although the process color printing inks are used, the process color patches were reproduced through combinations of three process color inks. The overprint colors

are in turn reproduced with major portions to the two process inks with smaller quantities of the third color of ink. An example would be the color blue, which theoretically would be reproduced with equal amounts of cyan and magenta. In reality, this would not be correct. The color blue would have a small amount of an LPC or the third color included. The smallest variation between the three different color processes should occur with the process/overprint colors.

The hard to print colors are defined as combinations of light and dark skin tones with several dark tertiary colors. The dark tertiary colors are defined as having a large amount of gray component compared to the amount of ink that would define the hue. An excellent example is the previously diagrammed olive green color. This group should experience the greatest variation between the three reproduction processes.

The last grouping is all three groups of color patches combined. If indeed there is a reduced shift in hue during variations of SID then the combined color patches of all three groups should reflect this hypothesis.

Shifts in hue are not the only things that are affected by varying amounts of SID. Dot gain also has a pronounced

effect. With increases in SID, dot size also increases. Dot gain is defined as the increase in dot size as a halftone image travels from films to the printed sheet. If the lithographic press was to experience a increase in SID, then an increase in dot gain would also be experienced.

The elimination of a press run was attempted in this research project. It was reasoned that the use of a DuPont ATM (Automatic Toning Machine) Chromalin processor could satisfactorily simulate the increase and decrease of SID of the lithographic press. To simulate SID and dot gain on the Chromalin processor, increases in toner densities were created by adjusting the processor speed. Though increases and decreases of .50-.55 in SID occurred, the standard 18% dot gain was only increased by 4%.[3] The increases and decreases of SID could be simulated, but the change or variations of dot gain could not. This increase in dot gain does not represent an accurate account of the actions of the SID and dot gain on the lithographic press.

The use of spacer material to increase dot spread might have been an alternative to an actual pressrun if a negative chromalin system was accessible. The spacers would cause light scatter during exposure, which in turn accounts for

---

[3] Pre-test, Electronic Color Imaging Laboratory, Rochester Institute of Technology, Rochester, New York.

dot growth. If spacers were to be used in the available positive system, a reversing affect of changing dot size (dot sharpening) would result. Dot sharpening is the reduction of dot size as the halftone image travels to the printed sheet. The high correlation between dot gain and SID and correlations between dot gain and shifts in hue can not be ignored. It was necessary to include a press run to incorporate the variability of the lithographic offset press.

With an increase in SID, the trap will also change. Trapping is the application of one ink film on top of another film of ink, which can have a pronounced affect of the shifts of hue on the lithographic press. If the SID of the second down color is greater than that of the first down color, the hue of that two-color overprint will tend to run closer to the second down color.[4] An example would be a cyan trapping over a magenta. If the SID of the second down color "overtraps" then the color will be "bluish red."

By definition, the first color down can be either wet or dry when the second color is applied. A dry trap would be more practical for eliminating the effect of trapping entirely. If a sheet fed press was used and the sheets were allowed to

---

[4] George W. Jorgensen, "Control of Color on Press: Overprints" GATF Research Project Report, no. 118, p. 3.

dry between colors, the dry trap would be possible. However, the variability of multi-color offset presses includes trapping along with dot gain. These problems need to be included with the ease of variability on the offset lithographic press. To put the GCR process to a realistic test requires a press run that closely approximates production conditions.

Slight discrepancies between the normal chromatic and GCR reproduction exist. The variation between the processes is a problem the scanner manufacturer's themselves continue to research. This variation did not affect this particular study. What this research project attempts to compare is the variation between the standard densities and variations of densities of a particular process. The A, B, and C processes were compared to a variation of themselves. Although slight discrepancies may be objectionable in comparing a GCR reproduction and an original normal chromatic separation, it does not play a major role in this study.

Chapter 4

CONCLUSIONS

The objective of this paper was to test the hypothesis that with variations of SID on the lithographic press, the GCR process reduces shift in hue over the normal chromatic color process. The McBeth Color Checker was reduced to four distinct and separate color groupings--neutral grays, process/overprint colors, hard to print colors, and all colors--to evaluate of the different areas of reproduction affected by the GCR process.

Instrumentation

Each of the color patches within the different groups was measured with a Hunter Lab Scan spectrocolorimeter. The first instrument reading was of the standard color patch, and X, Y, and Z color coordinates were stored as such. As a trial color patch was measured, changes in the X, Y, and Z coordinates were recorded and calculated to provide readings of Delta chroma, Delta lightness, and Delta hue. The measurements continued with each new color patch. The standard color patches were measured and trial X, Y, and Z

coordinates were obtained. Measurements of corresponding "variation" color patches provided X, Y, and Z coordinates whose combined calculation produced a Delta hue reading. These color patches were the variations of SID within each color process. That is to say that standard process color patch C4 was measured and the measurements stored. Corresponding color patches of C4 representing variations of SID were measured against the standard C4 reading and Delta hue values resulted. This procedure was repeated until all of the color patches 1-24 and each of the processes A, B, and C had corresponding Delta hue readings. This study focused on the shifts of hue on the lithographic press, so the Delta hue was selectively utilized.

A semi-log graph was created to plot changes in Delta hue against variations in SID and to provide a visual examination of the results. Using the x, y axis of a coordinate system, the x axis denoted the deviations of Delta hue and the y axis the logarithmic changes in SID. Both density and Delta hue values began at zero with positive and negative values resulting. The x axis of the graph paper moved out from the center in increments of +/- .10, .20, and .30 change in SID. The y axis moved out from the center in increments of +/- 0 to 40 units of Delta hue.

This plan allowed each graph to depict variations of the

normal chromatic, 60% GCR, and 100% GCR color processes as they relate to an ink adjustment of a particular color patch. If a particular process experienced reduced shifts in hue, its curve would be drawn closer to the y axis than the other processes. Thus, the three different reproduction processes could be compared.

Visual analysis of each graph included information on a specific color patch and that color patch's relationship to

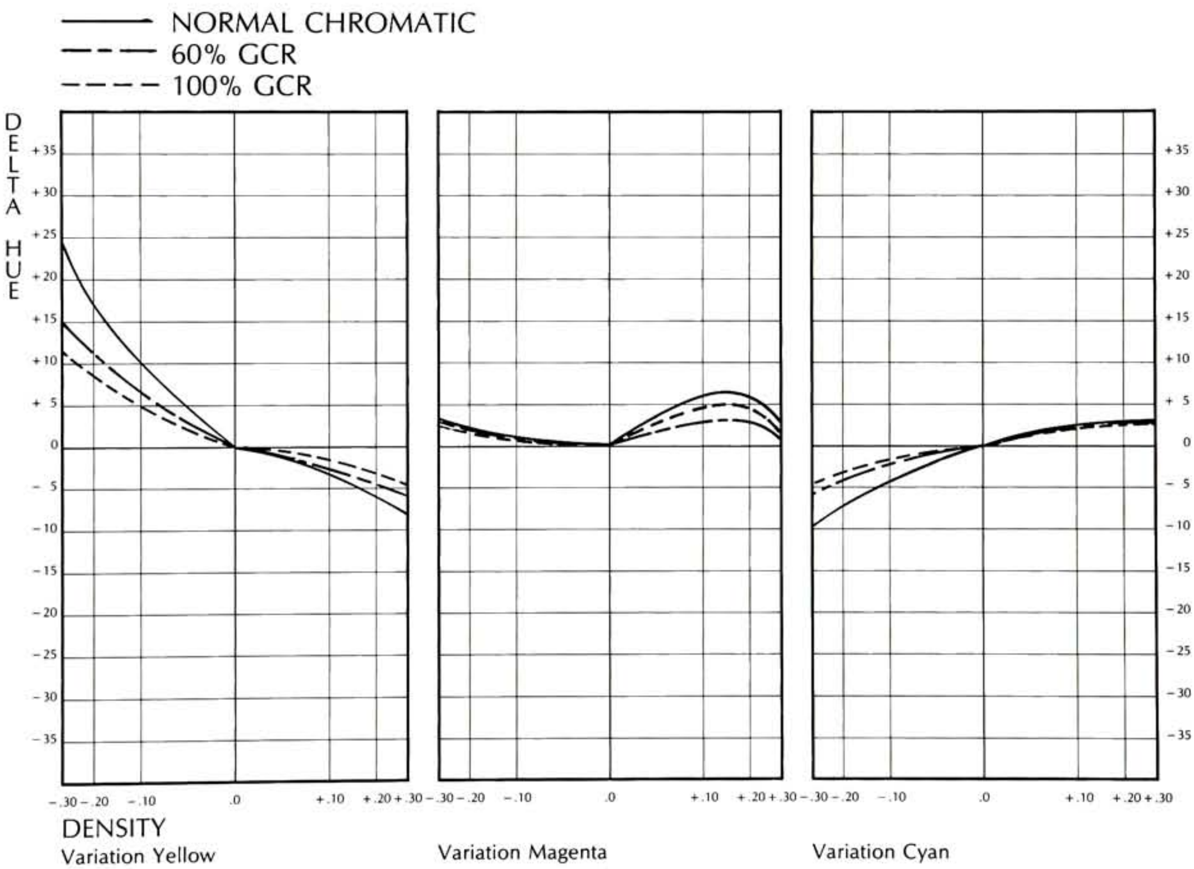

Figure 16. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #16 for the normal chromatic, 60% GCR, and the 100% GCR color process.

the other color printing processes. In Figure 16, for example, the graph represents color patch #16, which is the color green foliage.

The comparison of the different processes and densities of each process provide a judge of reduced variation with the GCR color process. Variations of the magenta and cyan inks produced somewhat reduced effects, but the results appear to be the same.

The actual color swatches for the variation yellow of color #16 reinforce the information listed in the graphs in Figure 16. The specific color patches for the yellow variation are mounted in Figure 17 and 18. Examination of the color patches for the 100% GCR, 60% GCR, and the normal chromatic process show that the GCR process does indeed reduce shifts in hue.

In all, 18 individual color patches were examined. With a visual comparison, it appeared that the 100% GCR was indeed a more stable process than the normal chromatic process, but what was more interesting is that the 60% GCR was noticeably more stable than the normal process. It is this researcher's opinion that from the graphs alone, the GCR (both the 100% and the 60%) are more stable than the normal chromatic color process.

This data does not quantify the difference between the color processes. A quantitative difference was accomplished through the use of a t-test. To determine statistically the significance of the variation in hue, an average of the total Delta hue readings was determined for each color grouping. This is to say that a mean value of Delta hue readings for the chromatic neutral gray was calculated as

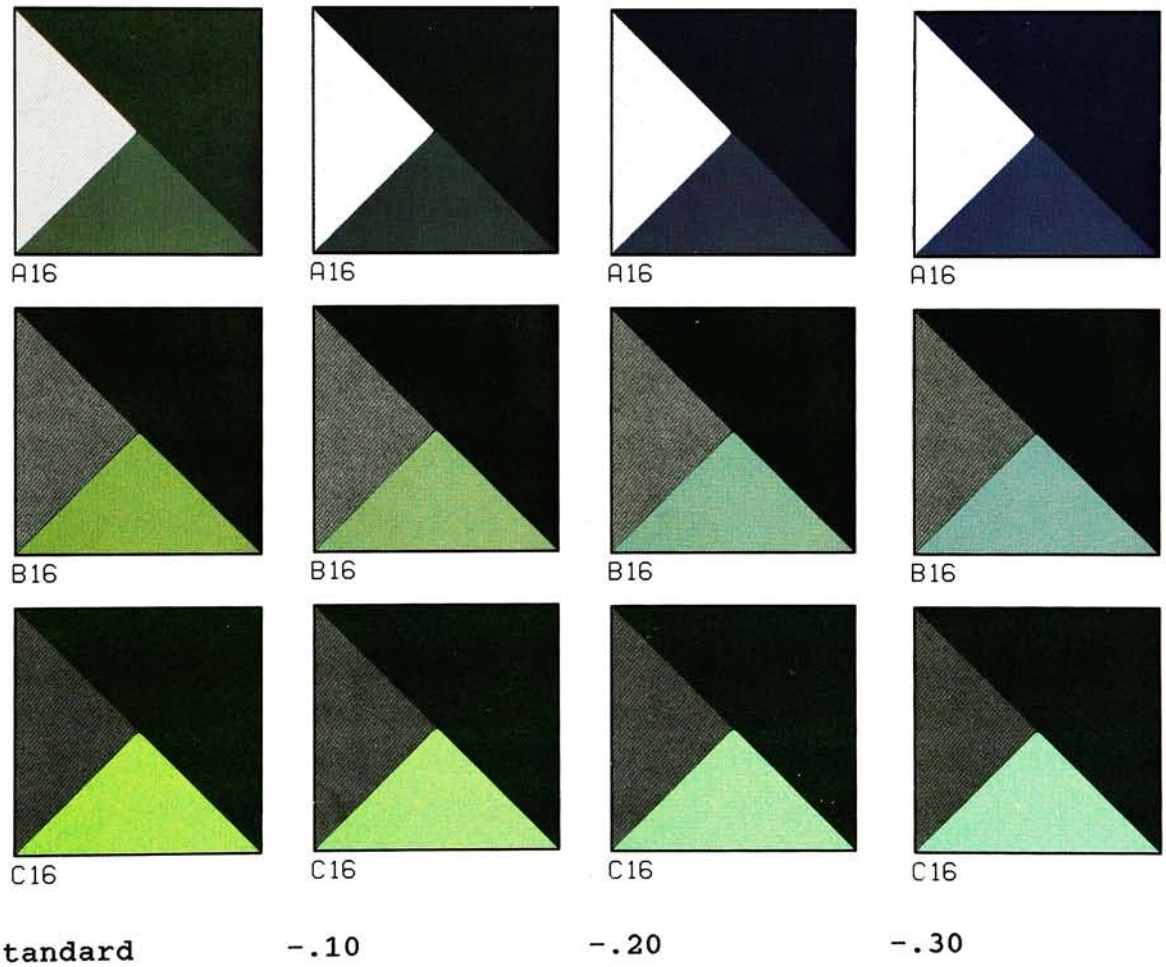

Figure 17. Examples of color patch #16 with standard densities and decreasing densities of the yellow ink for the 100% GCR, 60% GCR, and the normal chromatic processes.

well as a mean for the 60% neutral gray and the 100% GCR neutral gray color grouping. The neutral gray color grouping was the first to be evaluated. The test of variation between the two groups was accomplished with the use of a t-test, measuring the difference between two means. The t-test number of significance is based on the number of

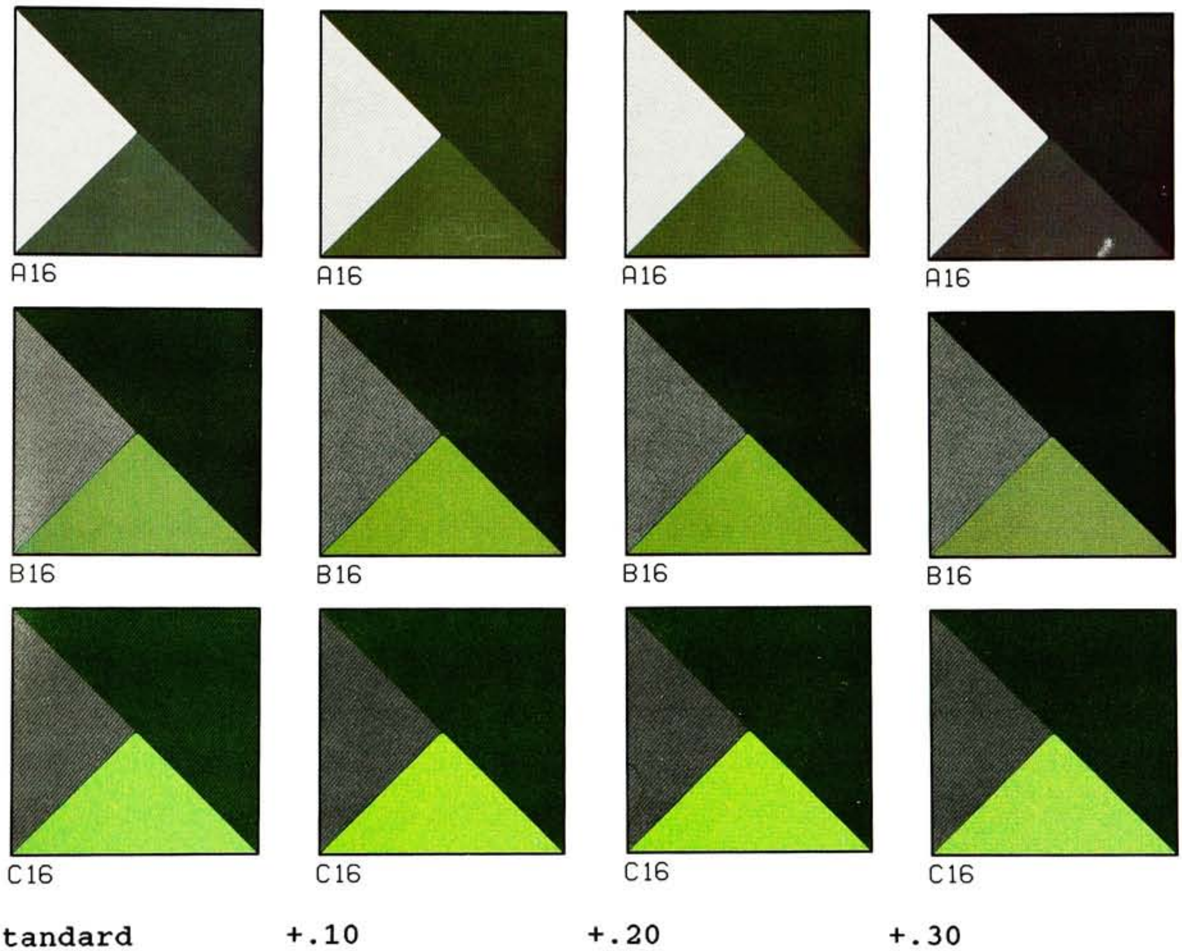

Figure 18. Examples of color patch #16 with standard densities and increasing densities of the yellow ink for the 100% GCR, 60% GCR, and the normal chromatic processes.

degrees of freedom. With the total number of replicants over 200 a infinite number of degrees of freedom was utilized. This particular test require a t-number higher than 1.65 to prove significance at the .05 confidence level.

The neutral gray color grouping provided the greatest level of significance of any of the groups tested. Both the 60% process and the 100% process significantly reduced shift of hue when compared to the normal chromatic process.

	t-value	% of freedom	A $\bar{x}$	B $\bar{x}$
A/B Process Comparison	4.49	214	2.92	1.50
	t-value	% of freedom	A $\bar{x}$	C $\bar{x}$
A/C Process Comparison	6.00	214	2.92	1.10

Figure 19. Statistical comparison between A and B processes and the A and C processes of the neutral gray color grouping

As expected the importance of gray balance in the reproduction of neutral gray tones can not be over emphasized with the use of the normal chromatic color process. Gray balance, the ability to print a neutral gray color with the three process inks, does no apply with a process that reproduces an original with only two colors plus black. With the increase use of UCA and decreasing percentages of GCR the importance of gray balance will return.

The second grouping was the process/two color overprint colors. The two color overprint colors were the blue,

	t-value	% of freedom	A x̄	B x̄
A/B Process Comparison	1.74	214	5.06	4.06
	t-value	% of freedom	A x̄	C x̄
A/C Process Comparison	3.01	214	5.06	3.39

Figure 20. Statistical comparison between A and B processes and the A and C processes of the process/overprint color grouping

green, and red. The comparison between the normal chromatic and the 100% GCR was significant with the normal and the 60% GCR comparison only slightly significant. This result was to be expected with the process/overprint color comparison.

The hard to print color grouping consisted of light and dark skin tones and dark tertiary colors of purple, purplish blue, foliage, and yellow green. (Figure 21)

	t-value	% of freedom	A x̄	B x̄
A/B Process Comparison	1.72	214	6.12	4.12
	t-value	% of freedom	A x̄	C x̄
A/C Process Comparison	2.02	214	6.12	3.80

Figure 21. Statistical comparison between A and B processes and the A and C processes of the hard to print color grouping

The hard to print color grouping consisted of light and dark skin tones and dark tertiary color of purple, purplish blue, foliage, and yellow green. This group experienced the smallest variation of all the groups. Though both comparisons were significant, the normal/60% comparison was only slightly significant. These results came as a surprise considering the large variations expected with the hard to print color grouping. The hard to print color grouping was defined as large amount of gray component compared to the amount of ink that defines the hue.

Certain color patches may have skewed the results to produce a low significance to the hard to print grouping. It seems unlikely a group that would provide low results of significance could be effectively used as the visual evaluation in this research. The color patch, foliage green used as the visual comparison between the different processes provided a strong example of the reduction in shift in hue of the GCR process. This color patch seems to contradict the result obtained in the statistical testing. It is this researchers opinion that the color of purplish blue (#7), light skin (#8), and yellow green (#9) were incorrectly added to the hard to print color grouping and decreased the level of significance in this study.

The last grouping was the category of all colors. This

includes combinations of all previous color groupings. These combinations are very different from one another and provide a difficult test of significance. With the combination of all colors grouped as replicants, the necessary requirement to obtain a reduction in a shift in hue increases. The testing produced results that were significant in both comparisons. This supports the hypothesis that the GCR process does indeed reduce shifts in hue on the lithographic press. (Figure 22)

	t-value	% of freedom	A $\bar{x}$	B $\bar{x}$
A/B Process Comparison	3.21	645	4.70	3.24
	t-value	% of freedom	A $\bar{x}$	C $\bar{x}$
A/C Process Comparison	4.33	645	4.70	2.77

Figure 22. Statistical comparison between A and B processes and the A and C processes of the all colors

Implications

The results of research have begun to provide insight into the applications of the use of GCR in the printing industry. As color separators acquire equipment capable of GCR, the process is expected to grow. With that growth is a need for

continued research broadening the understanding of the GCR process.

Though the 100% GCR process is not recommended because of the lack of sufficient density in the dark shadow areas, there was some question of the processes ability to reduce shifts in hue with reduced percentages of GCR. Through this testing it has been shown that even with the reduced percentages of GCR there are significant reductions in shifts of hue on the lithographic press. The reduction in shifts in hue are greater with the 100% process but the advantages of the smaller percentages of GCR outweigh its use.

Shifts in hue were the focus of this research but the implications of the reduction in shift is hue are many fold. As speeds of printing press, the cost of printing substrate, and the need for shorter makereadies continues the GCR process gains strength. The use of the GCR process will not only decrease makeready but reduce down-time relating to color variation. These advantages provide reduced costs and warrant the continued expansion of the GCR process.

Chapter 5

Recommendations

Through the course of this research questions have surface concerning the GCR process. Limits of time and the scope of the study has made it impossible to address questions outside the original hypothesis. These questions will be listed below in hope that they may provide direction for persons interested in further research on the GCR process. These questions currently remain while others are asked as the GCR process gains popularity.

1. What percentage of GCR is the most efficient in terms of shifts in hue? With the understanding of the limitations in the use of the 100% GCR process what amount of GCR should be recommended for the printing industry.

2. How can UCA be best utilized with the changes in the amounts of GCR? What would be the recommendation to a standard setting for UCA be used with the recommended GCR setting.

BIBLIOGRAPHY

General References

Billmeyer, Fred W. Jr. Saltzman, Max. 1976. Principles of Color Technology. John Wiley and Sons.

Bruno, Mike. 1985. "Achromatics, Four Color Printing that isn't." American Printer. Jan. vol 194.

Hardy, A. C., Wurzburg, F. L. Jr. 1948. "Color Correction in Color Printing." Journal of the Optical Society of America. vol 38.

Jorgensen, George W. "Control of Color on Press: Overprints." GATF Research Project Report. no. 118. p. 3.

Keppler, Gunter. 1982. Klischograph. Dr. -Ing. R. Gmbh. Kiel, Germany.

Kueppers, Harald. 1982. The Basic Law of Color Theory. Barron's. Woodbury, New York

Kueppers, Harald. 1982. Color Atlas, A Practical Guide to Color Mixing. Barron's. Woodbury, New York

Phillips, John L. 1982. Statistical Thinking. W. H. Freeman and Company

Sigg, Franz. 1984. "On Second Thought, Lets Call it Gray Component Replacement." T+E Newsletter. vol. 12. no. 6.

Technical Association for the Graphic Arts. 1954. Proceeding of the Sixth Annual Meeting. ""A Color Correction Process." Technical Association for the Graphic Arts. 1984. Proceeding of the Thirty-Sixth Annual Meeting. "Programmed and Complementary Color Reduction."

Technical Association for the Graphic Arts. 1984. Proceeding of the Thirty-Sixth Annual Meeting. "Investigation into the Application of Achromatic Synthesis to the Printing Industry.

Southworth, Miles. 1981. Color Separation Techniques. 2nd ed. Graphic Arts Publishing. Livonia, New York

Southworth, Miles. 1981. "Quality Control Scanner. Graphic Arts Publishing. Livonia, New York

Yule, J. A. 1967. Principles of Color Reproduction. John Wiley and Sons, Inc.

APPENDIX A

Graphs depicting variations of yellow, magenta, and cyan ink for color patches used in comparing the normal chromatic, 60% GCR, and the 100% GCR color process.

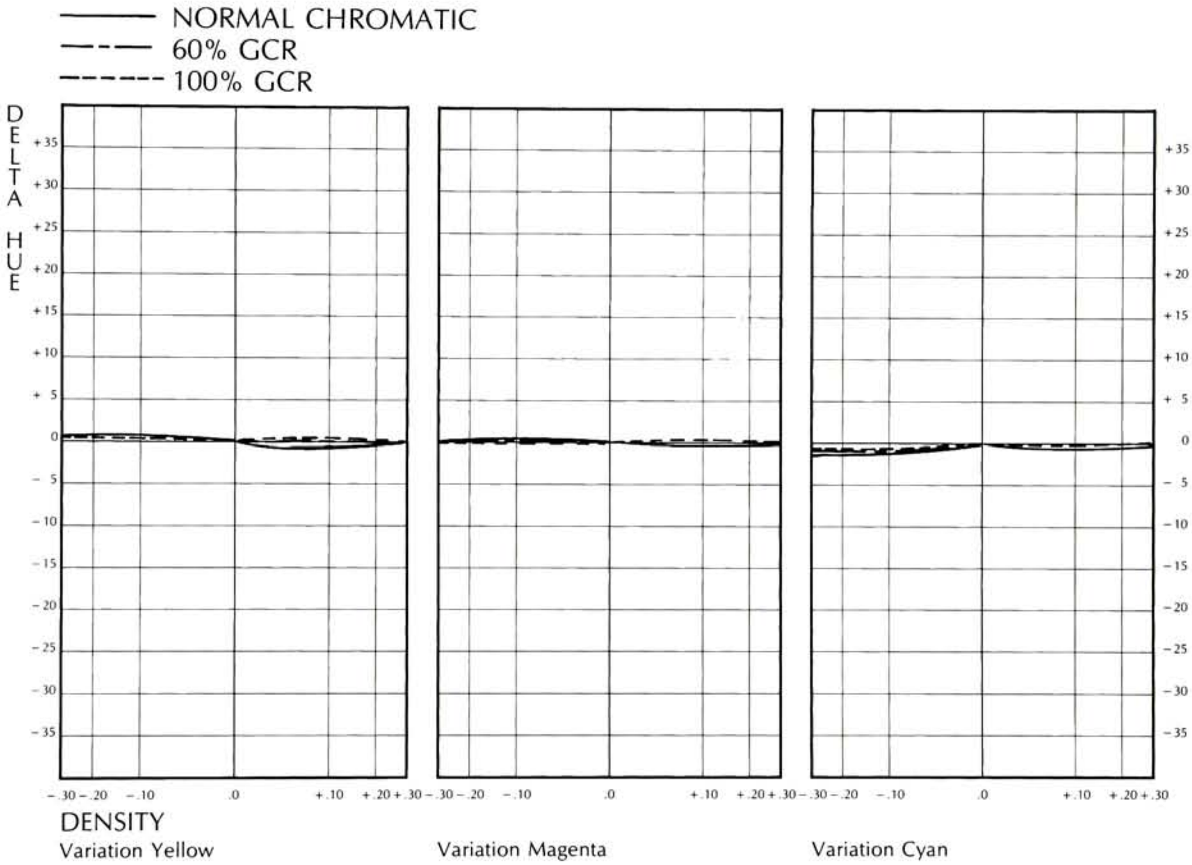

Figure 23. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #1 for the normal chromatic, 60% GCR, and the 100% GCR color process.

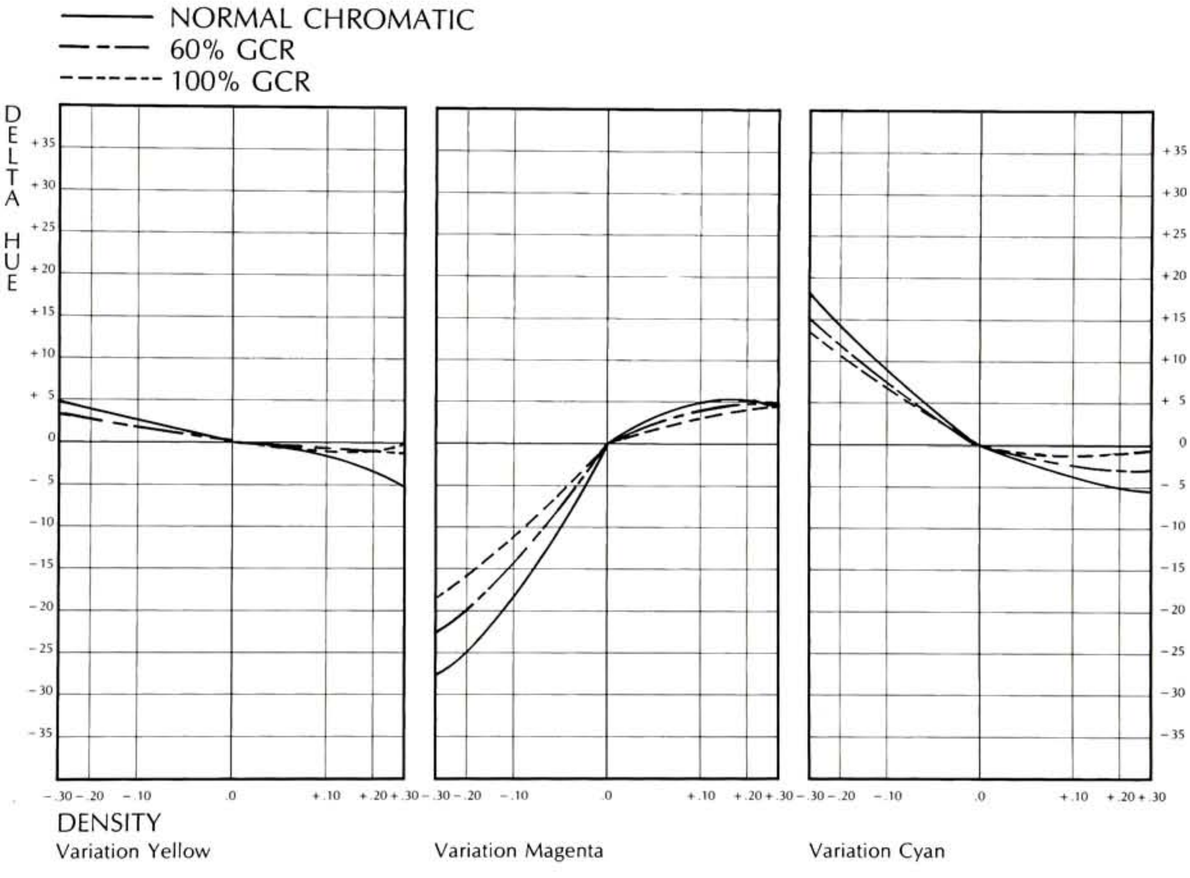

Figure 24. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #2 for the normal chromatic, 60% GCR, and the 100% GCR color process.

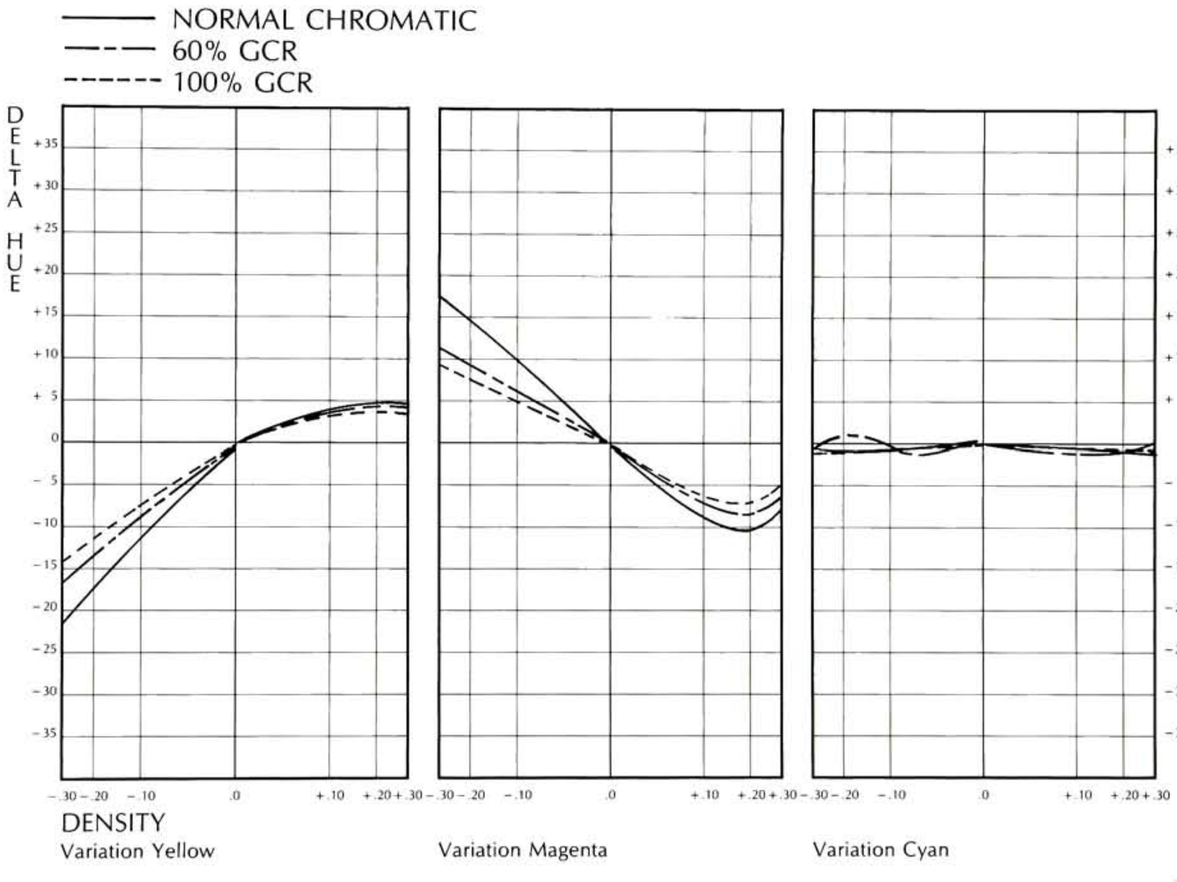

Figure 25. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #4 for the normal chromatic, 60% GCR, and the 100% GCR color process.

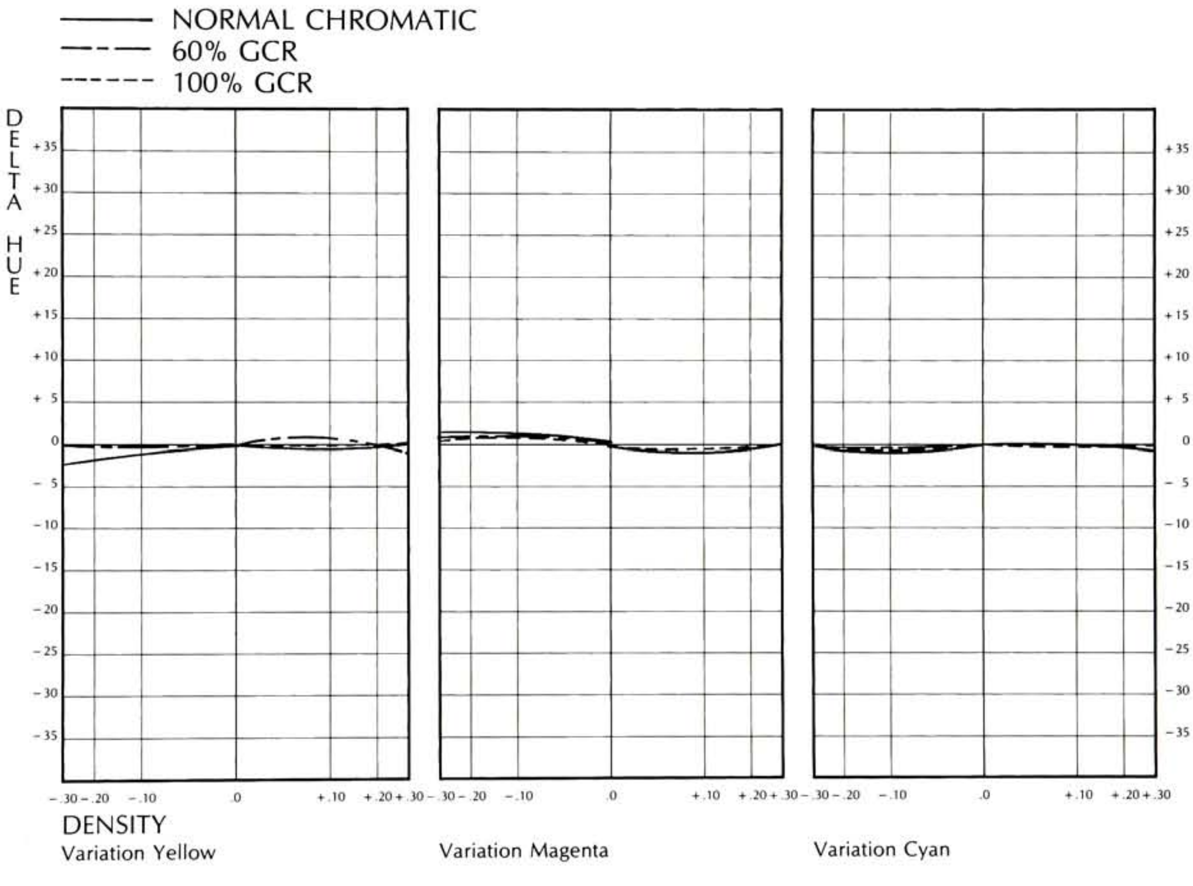

Figure 26. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #5 for the normal chromatic, 60% GCR, and the 100% GCR color process.

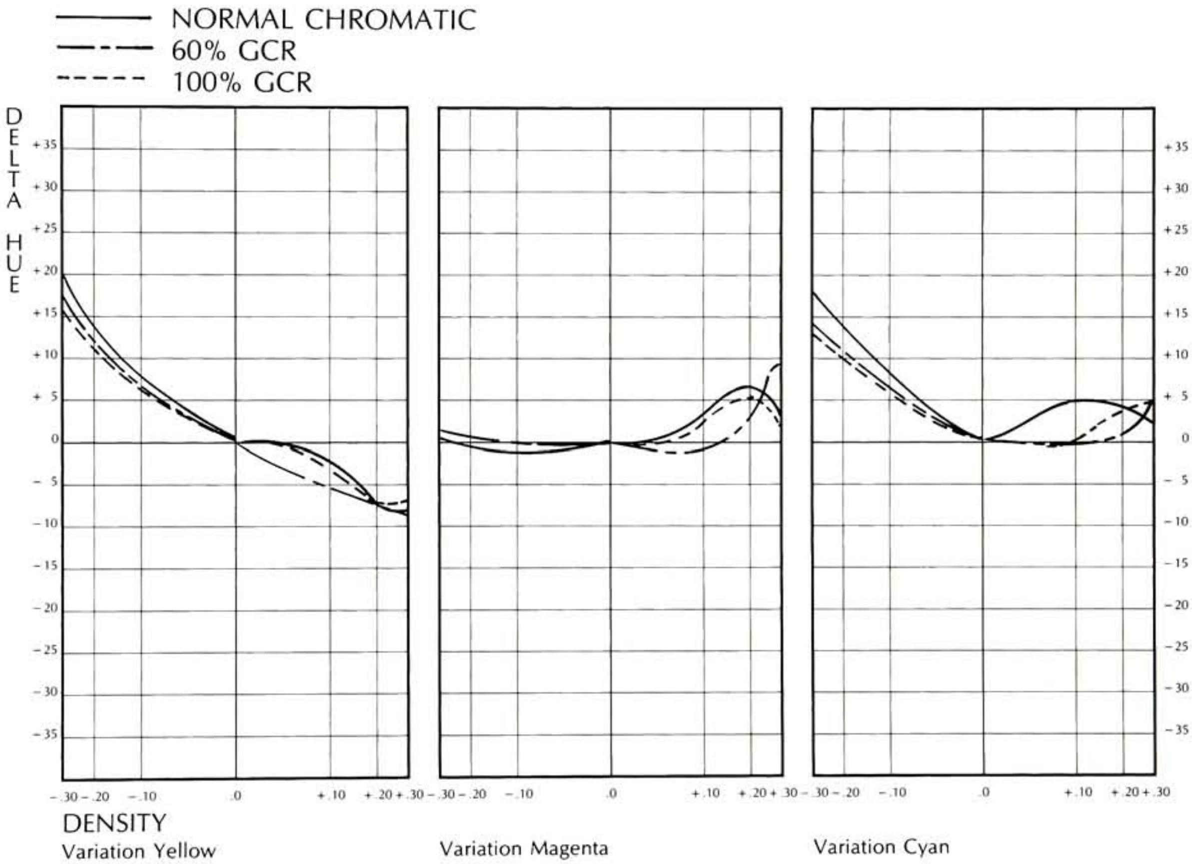

Figure 27. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #6 for the normal chromatic, 60% GCR, and the 100% GCR color process.

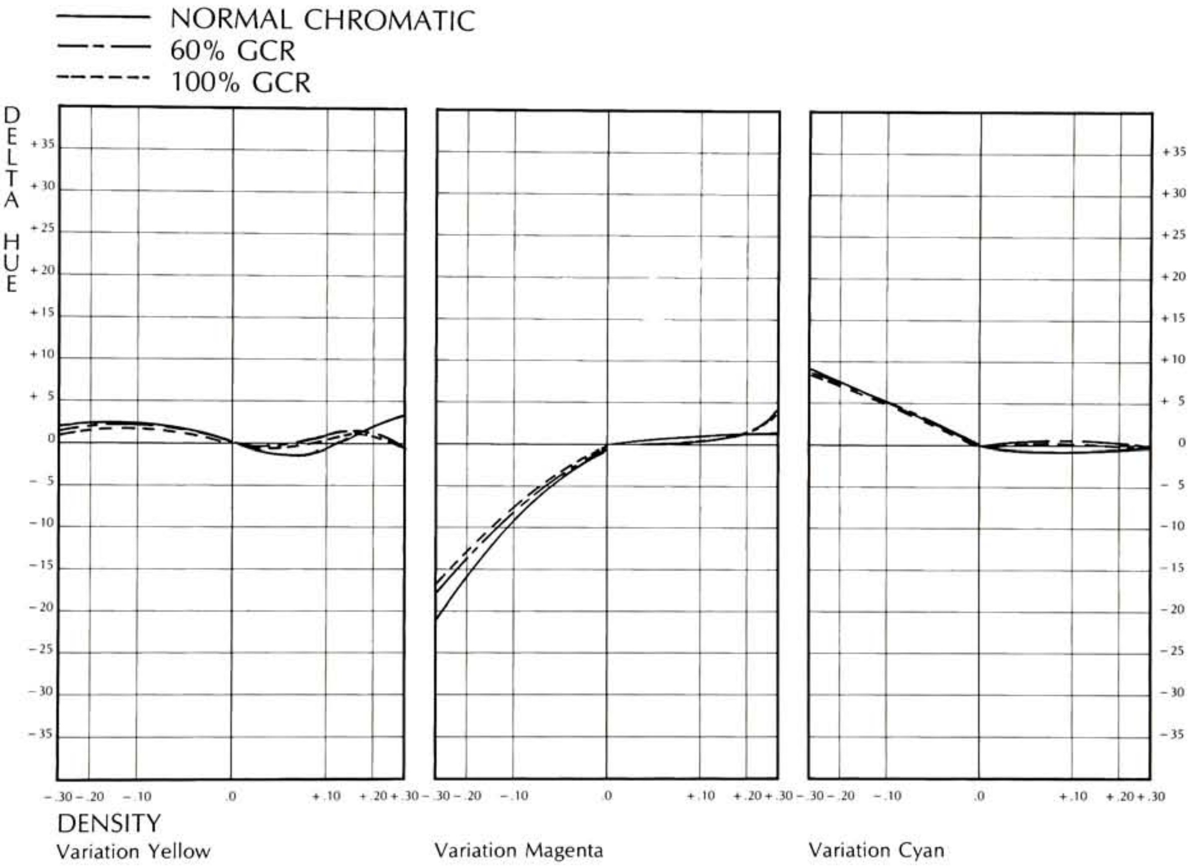

Figure 28. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #7 for the normal chromatic, 60% GCR, and the 100% GCR color process.

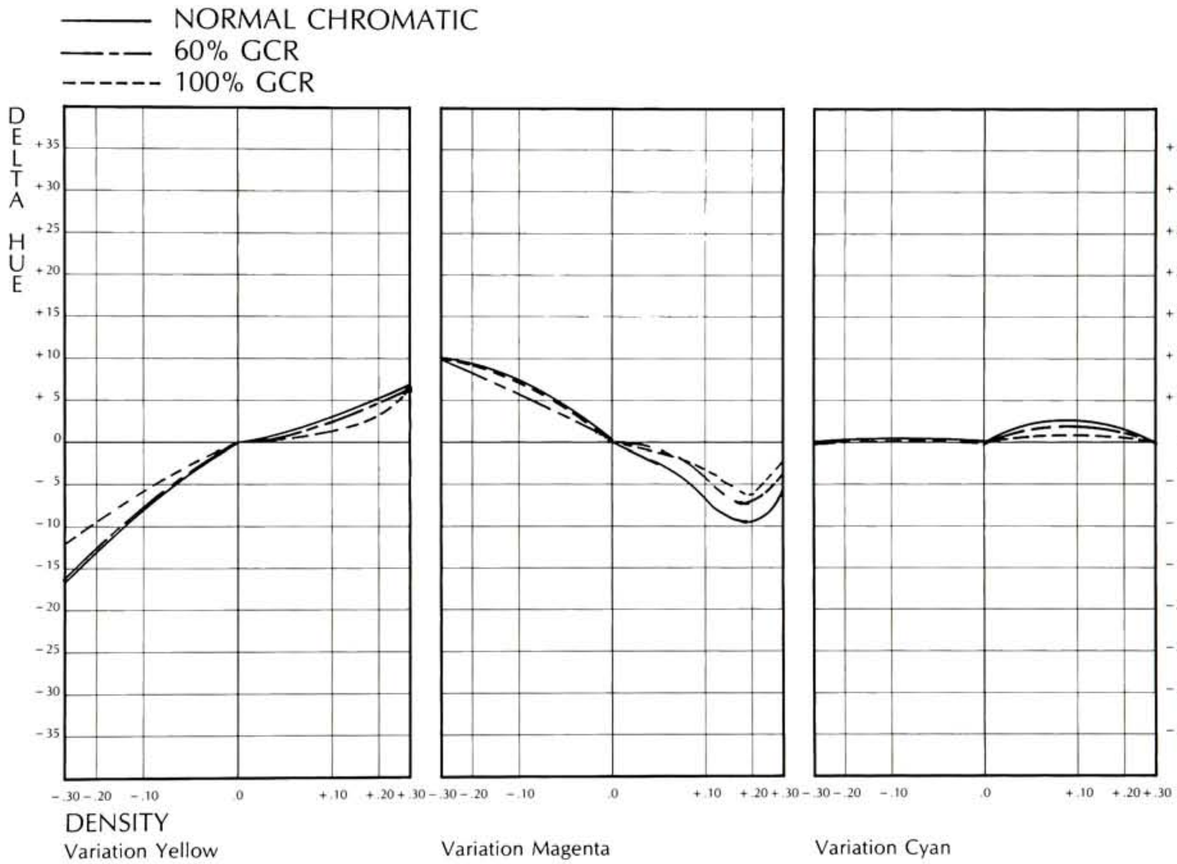

Figure 29. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #8 for the normal chromatic, 60% GCR, and the 100% GCR color process.

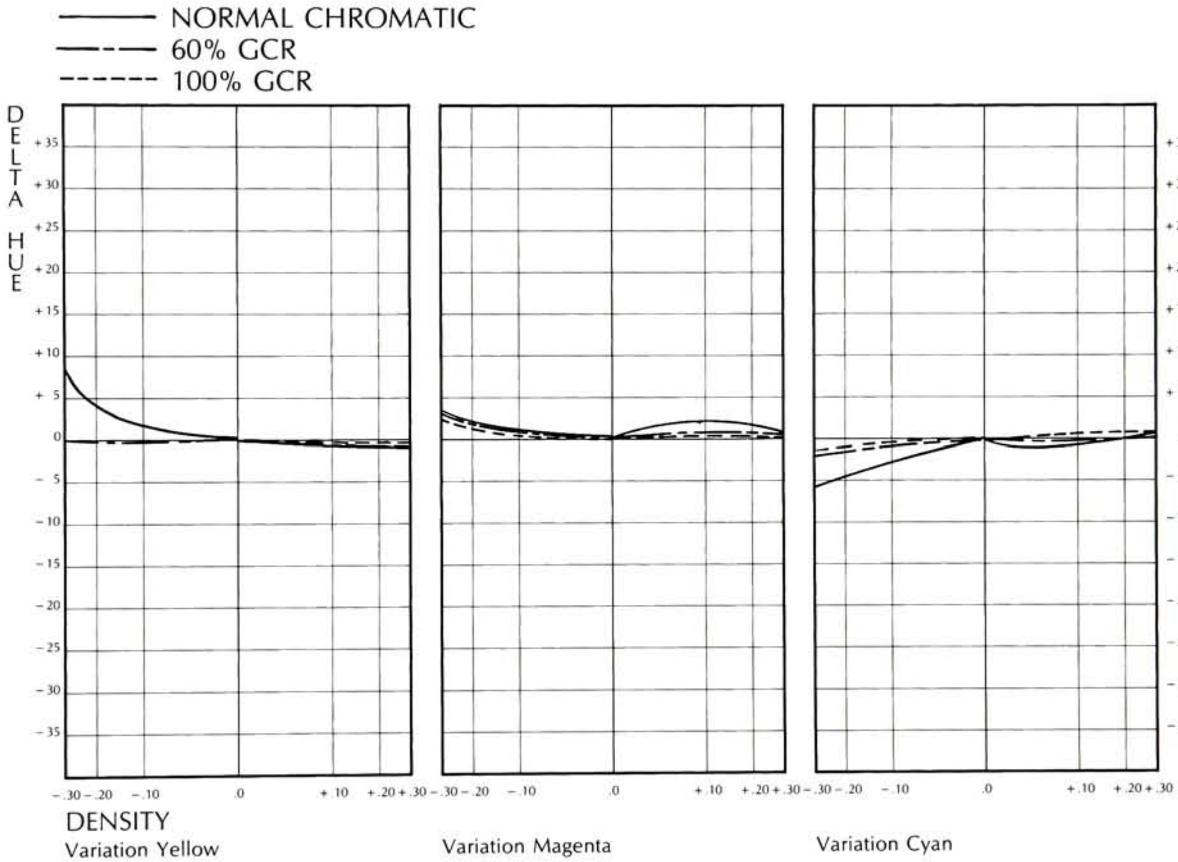

Figure 30. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #9 for the normal chromatic, 60% GCR, and the 100% GCR color process.

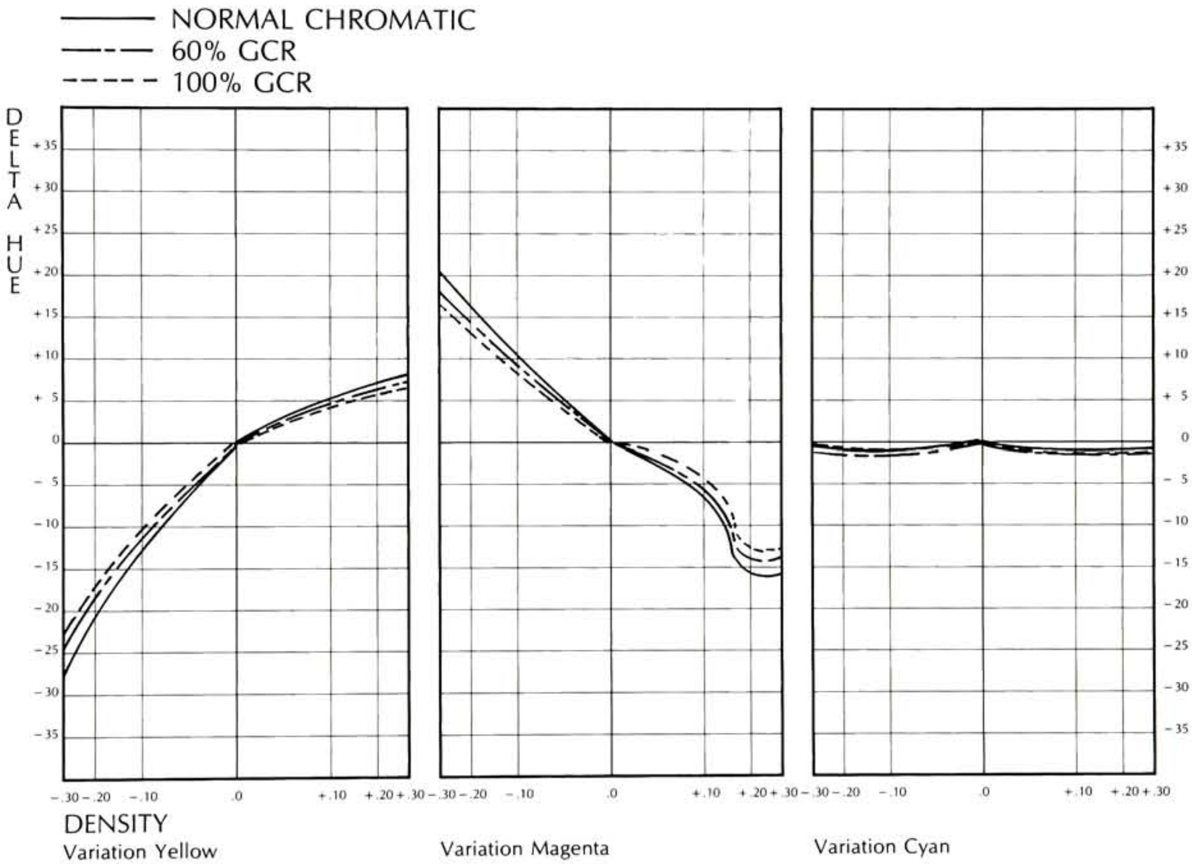

Figure 31. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #10 for the normal chromatic, 60% GCR, and the 100% GCR color process.

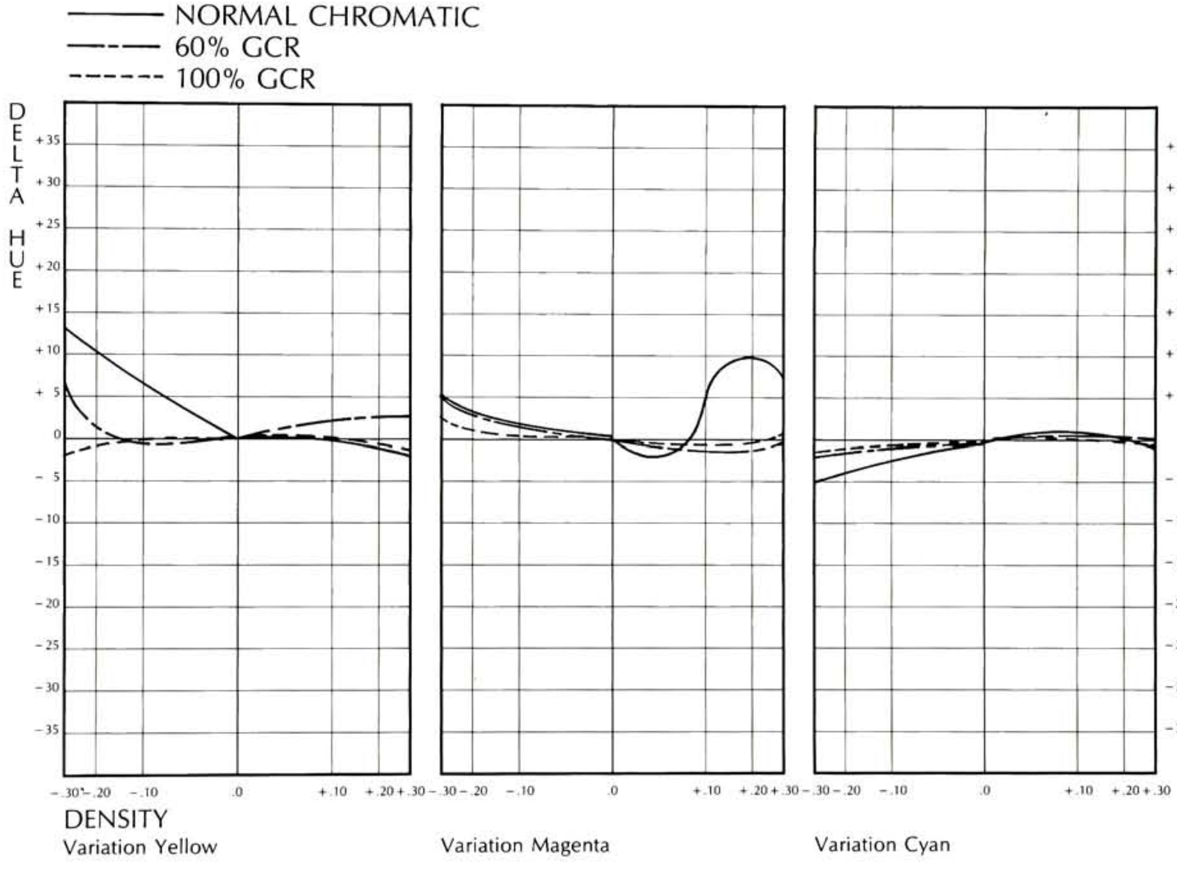

Figure 32. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #13 for the normal chromatic, 60% GCR, and the 100% GCR color process.

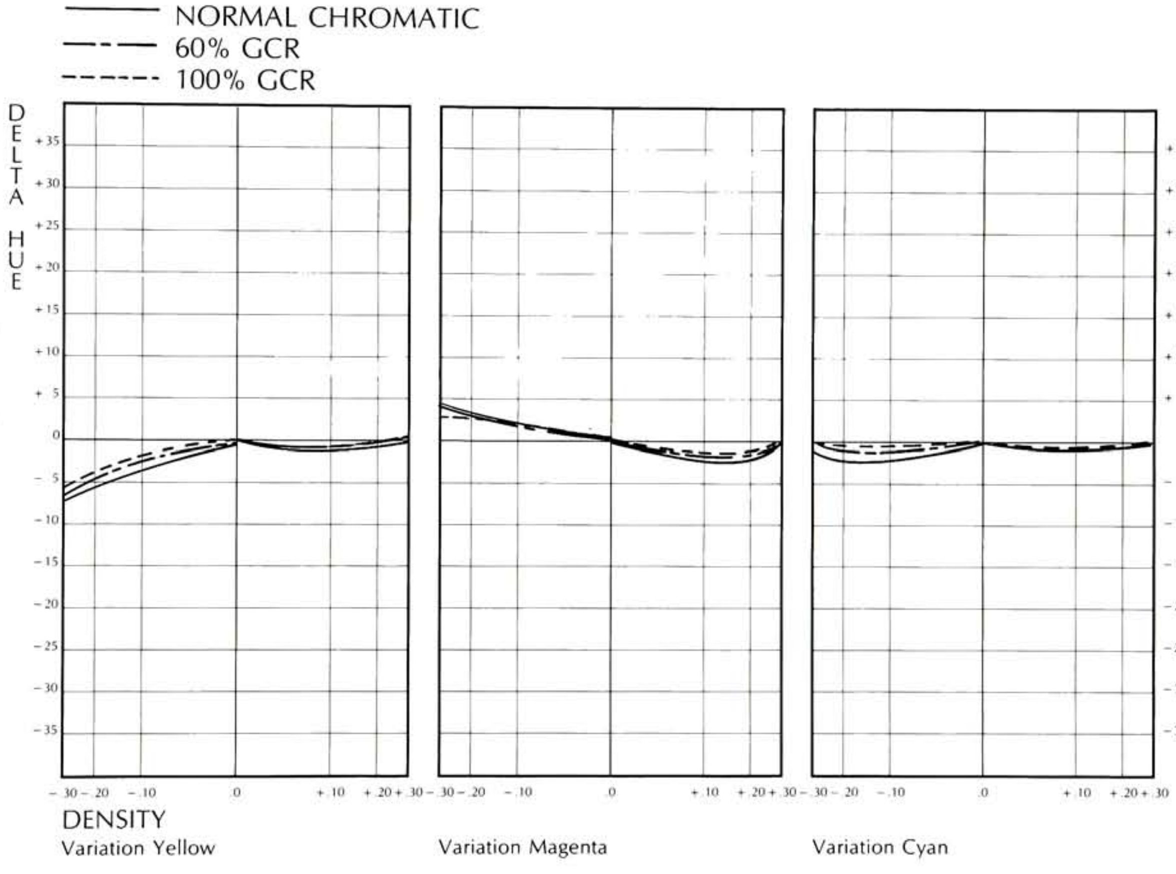

Figure 33. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #14 for the normal chromatic, 60% GCR, and the 100% GCR color process.

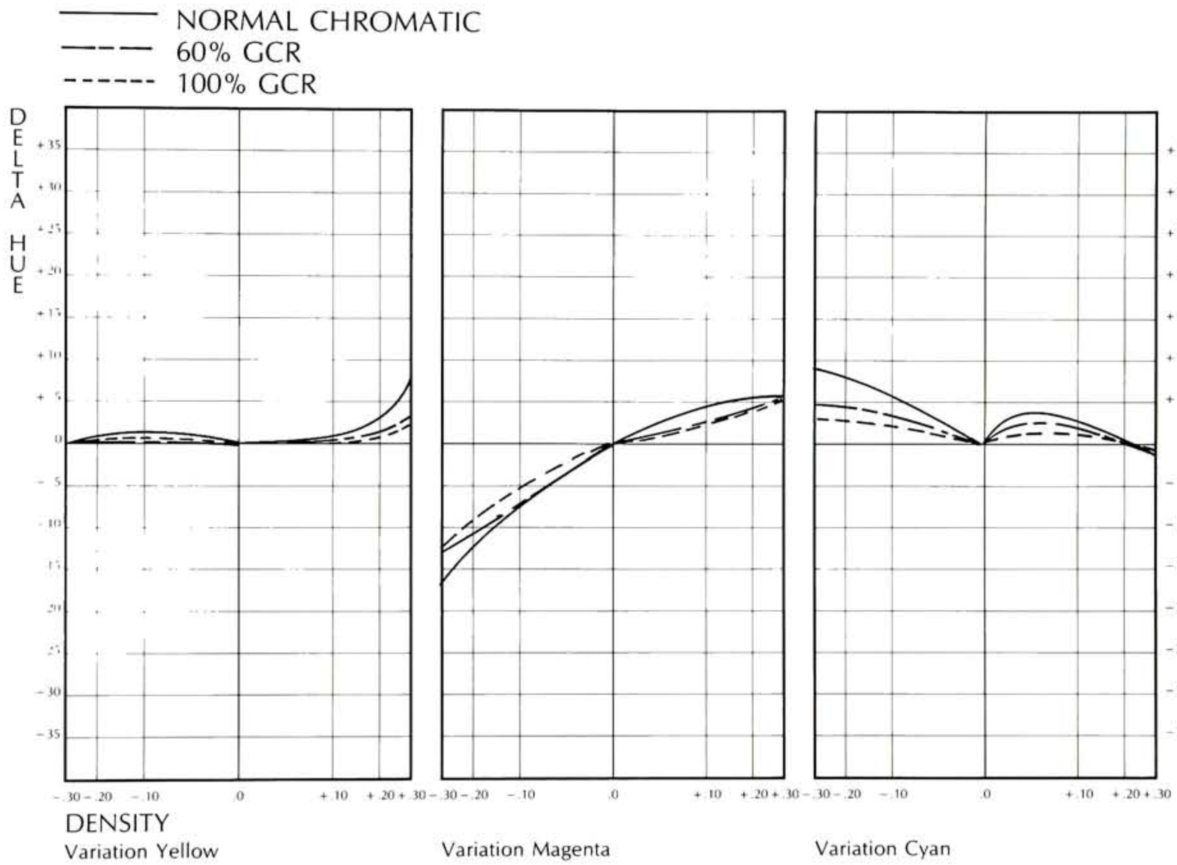

Figure 34. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #15 for the normal chromatic, 60% GCR, and the 100% GCR color process.

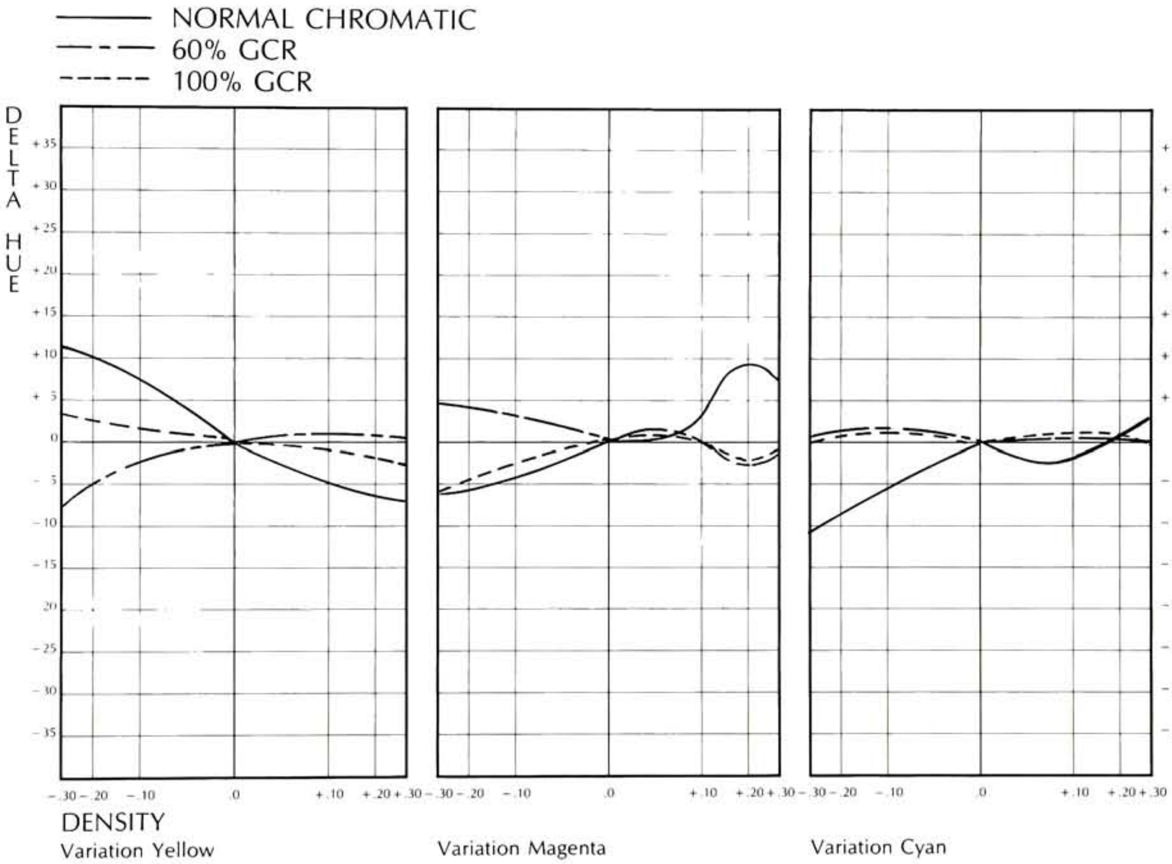

Figure 35. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #17 for the normal chromatic, 60% GCR, and the 100% GCR color process.

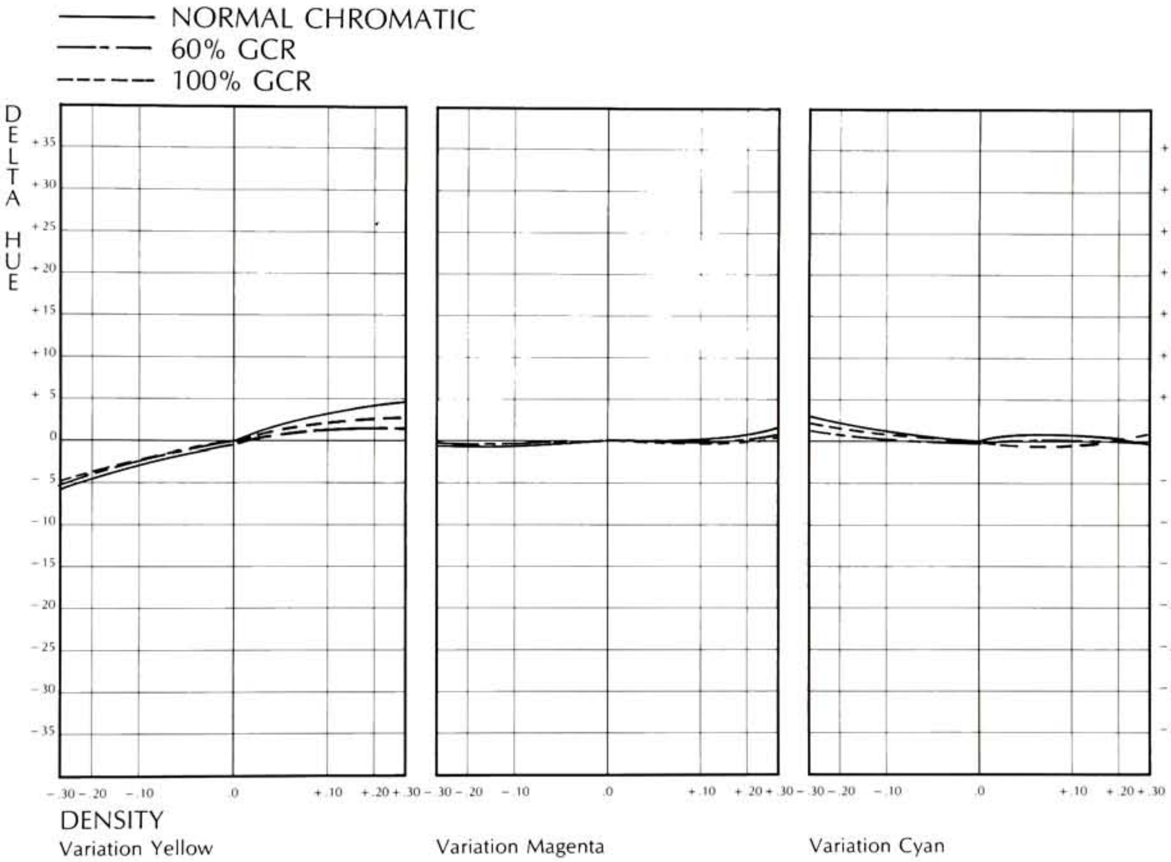

Figure 36. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #18 for the normal chromatic, 60% GCR, and the 100% GCR color process.

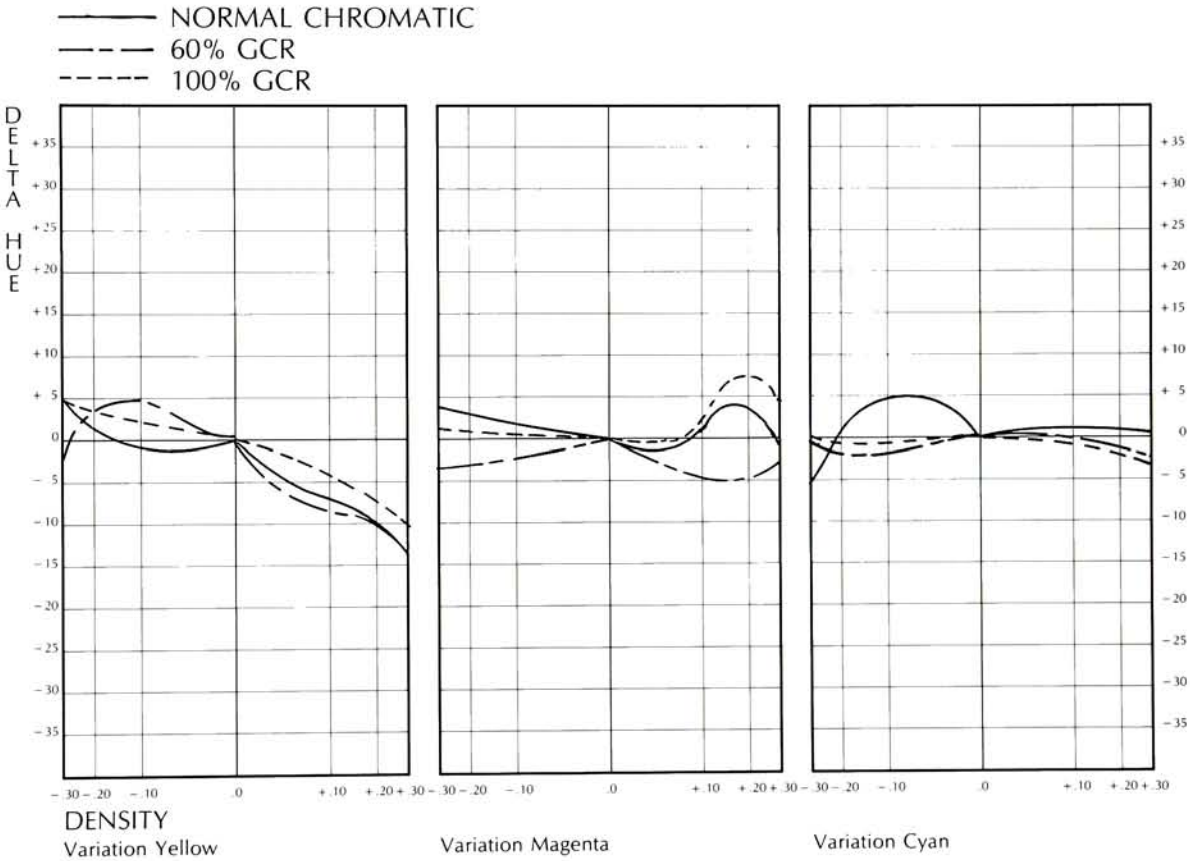

Figure 37. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #19 for the normal chromatic, 60% GCR, and the 100% GCR color process.

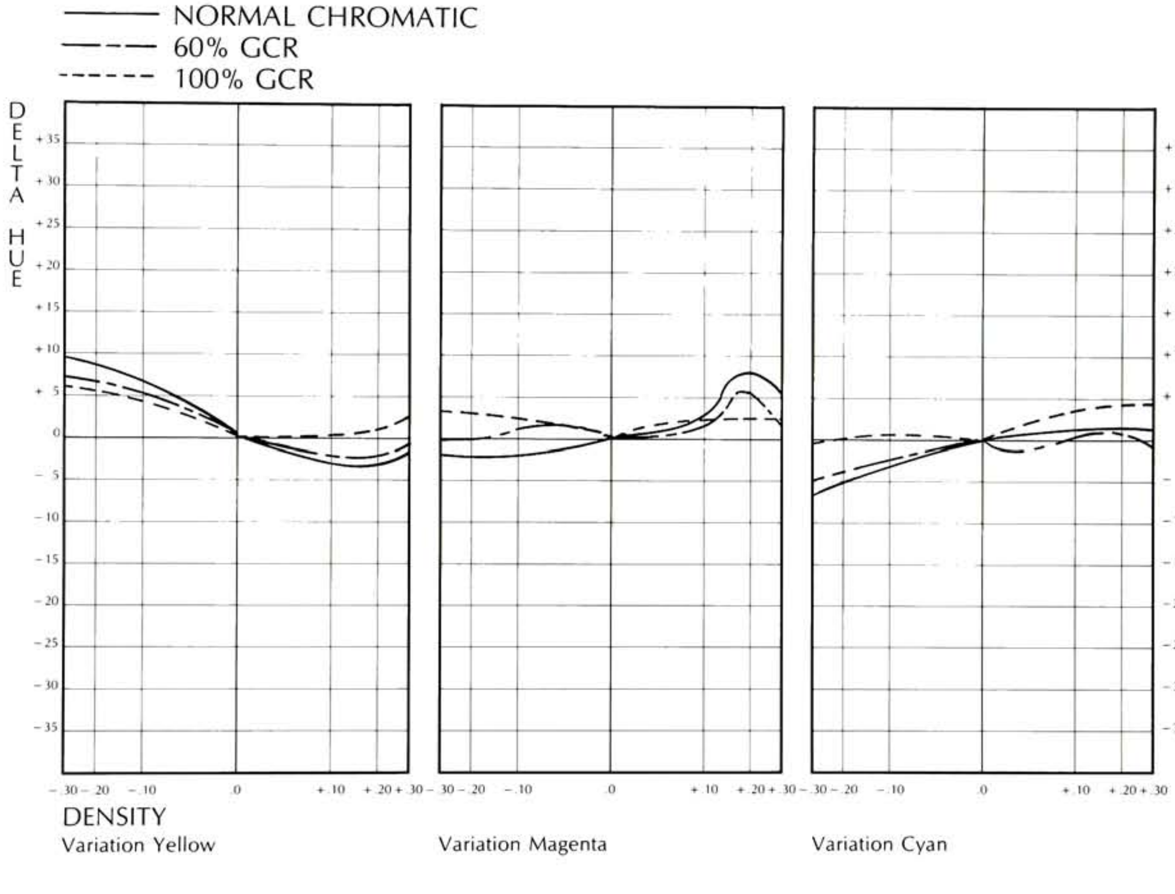

Figure 38. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #21 for the normal chromatic, 60% GCR, and the 100% GCR color process.

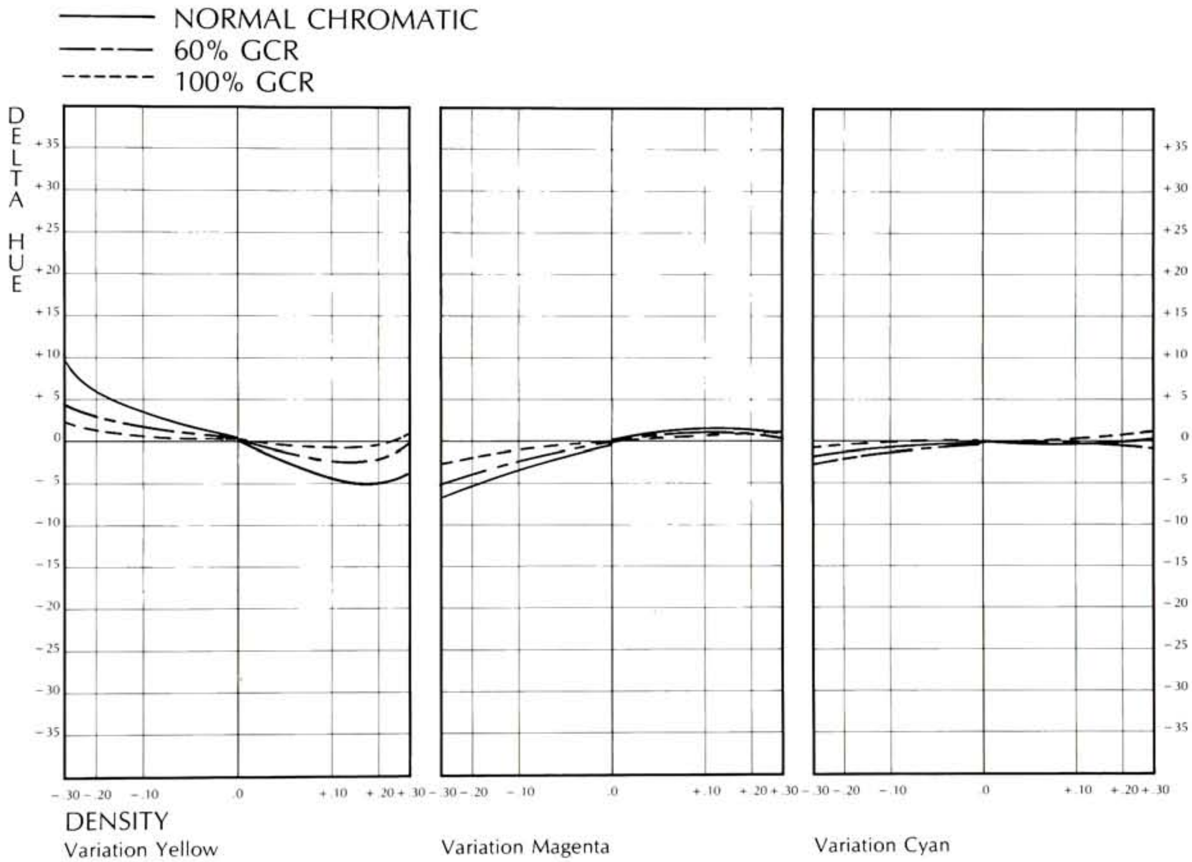

Figure 39. Graphs depicting variations of yellow, magenta, and cyan ink for color patch #22 for the normal chromatic, 60% GCR, and the 100% GCR color process.

APPENDIX B

Table 1. Data obtained from variations of yellow, magenta, and cyan ink for the A process, neutral gray color grouping.

Color Patch	Density Variations	Delta Hue Reading
1	-.30	0.35
1	-.20	0.88
1	-.10	0.00
1	-.30	-1.71
1	-.20	-1.39
1	-.10	-0.80
1	-.30	1.09
1	-.20	1.03
1	-.10	1.66
1	.30	-1.01
1	.20	-0.02
1	.10	-1.05
1	.30	-0.67
1	.20	-0.03
1	.10	-0.32
1	.30	-0.49
1	.20	-0.03
1	.10	-0.58
5	-.30	-2.08
5	-.20	-1.20
5	-.10	-1.02
5	-.30	-0.98
5	-.20	-1.37
5	-.10	-0.74
5	-.30	2.89
5	-.20	2.83
5	-.10	1.85
5	.30	0.50
5	.20	0.34
5	.10	0.41
5	.30	-0.16
5	.20	-0.12
5	.10	-0.49
5	.30	-0.67
5	.20	-0.58
5	.10	-0.93
9	-.30	9.19
9	-.20	1.42
9	-.10	-1.52
9	-.30	-4.63

Color Patch	Density Variations	Delta Hue Reading
9	-.20	-3.28
9	-.10	-2.14
9	-.30	3.36
9	-.20	1.91
9	-.10	2.36
9	.30	-2.66
9	.20	-1.43
9	.10	-2.92
9	.30	-1.79
9	.20	0.20
9	.10	-1.04
9	.30	-3.50
9	.20	-4.40
9	.10	-2.53
13	-.30	12.81
13	-.20	9.49
13	-.10	5.67
13	-.30	-3.74
13	-.20	-3.45
13	-.10	-1.66
13	-.30	4.54
13	-.20	2.88
13	-.10	2.34
13	.30	-1.30
13	.20	-1.44
13	.10	-0.15
13	.30	1.30
13	.20	2.30
13	.10	-0.62
13	.30	-4.31
13	.20	8.99
13	.10	-1.55
17	-.30	11.26
17	-.20	9.13
17	-.10	6.08
17	-.30	-9.79
17	-.20	-7.64
17	-.10	-5.76
17	-.30	-3.52
17	-.20	-3.05
17	-.10	-2.41
17	.30	-6.19
17	.20	-5.85
17	.10	-4.50
17	.30	0.61
17	.20	0.41
17	.10	-4.81
17	.30	7.36
17	.20	10.13

Color Patch	Density Variations	Delta Hue Reading
17	.10	0.16
21	-.30	9.30
21	-.20	7.82
21	-.10	5.18
21	-.30	-6.60
21	-.20	-4.85
21	-.10	-3.11
21	-.30	-1.73
21	-.20	-1.88
21	-.10	-1.87
21	.30	-3.67
21	.20	-3.85
21	.10	-1.15
21	.30	0.72
21	.20	1.40
21	.10	-0.33
21	.30	4.64
21	.20	7.95
21	.10	-0.02

Table 2. Data obtained from variations of yellow, magenta, and cyan ink for the B process, neutral gray color grouping.

Color Patch	Density Variations	Delta Hue Reading
1	-.30	1.44
1	-.20	0.69
1	-.10	0.89
1	-.30	-0.76
1	-.20	-0.43
1	-.10	-0.37
1	-.30	1.53
1	-.20	1.09
1	-.10	1.55
1	.30	-0.76
1	.20	-0.02
1	.10	-0.36
1	.30	0.26
1	.20	0.33
1	.10	0.12
1	.30	-0.17
1	.20	0.52
1	.10	-0.11
5	-.30	0.58
5	-.20	-0.01
5	-.10	0.07
5	-.30	-1.13
5	-.20	-1.21
5	-.10	-0.64
5	-.30	2.20
5	-.20	1.65
5	-.10	2.30
5	.30	-0.73
5	.20	-0.36
5	.10	0.72
5	.30	-0.17
5	.20	-0.27
5	.10	-0.60
5	.30	-0.32
5	.20	0.13
5	.10	-0.90
9	-.30	-0.39
9	-.20	-0.47
9	-.10	0.04
9	-.30	-0.91
9	-.20	-0.66
9	-.10	-0.49
9	-.30	2.63

Color Patch	Density Variations	Delta Hue Reading
9	-.20	1.58
9	-.10	1.44
9	.30	-0.86
9	.20	-0.12
9	.10	-0.74
9	.30	0.48
9	.20	0.82
9	.10	0.06
9	.30	-1.12
9	.20	-0.97
9	.10	-0.45
13	-.30	5.25
13	-.20	-2.38
13	-.10	-0.41
13	-.30	-0.30
13	-.20	-0.44
13	-.10	0.37
13	-.30	4.81
13	-.20	3.20
13	-.10	3.60
13	.30	2.39
13	.20	2.25
13	.10	1.93
13	.30	1.76
13	.20	1.19
13	.10	0.55
13	.30	-0.55
13	.20	-2.19
13	.10	0.00
17	-.30	-7.43
17	-.20	-4.14
17	-.10	-1.31
17	-.30	0.51
17	-.20	0.97
17	-.10	1.02
17	-.30	4.52
17	-.20	4.16
17	-.10	1.90
17	.30	1.96
17	.20	1.78
17	.10	1.90
17	.30	3.10
17	.20	2.75
17	.10	1.69
17	.30	-0.63
17	.20	-4.47
17	.10	1.82
21	-.30	7.19
21	-.20	5.72

Color Patch	Density Variations	Delta Hue Reading
21	-.10	3.30
21	-.30	-3.38
21	-.20	-2.96
21	-.10	-1.98
21	-.30	1.51
21	-.20	0.88
21	-.10	1.74
21	.30	-1.13
21	.20	-1.77
21	.10	-1.21
21	.30	0.57
21	.20	-0.09
21	.10	-1.24
21	.30	-2.71
21	.20	5.54
21	.10	0.15

Table 3. Data obtained from variations of yellow, magenta, and cyan ink for the C process, neutral gray color grouping.

Color Patch	Density Variations	Delta Hue Reading
1	-.30	0.99
1	-.20	0.61
1	-.10	0.24
1	-.30	-0.76
1	-.20	-0.71
1	-.10	-0.62
1	-.30	1.04
1	-.20	1.03
1	-.10	0.76
1	.30	-0.38
1	.20	-0.82
1	.10	-0.10
1	.30	0.41
1	.20	0.26
1	.10	-0.26
1	.30	-0.34
1	.20	0.23
1	.10	-0.35
5	-.30	1.03
5	-.20	0.65
5	-.10	0.76
5	-.30	-0.80
5	-.20	-0.73
5	-.10	0.01
5	-.30	1.24
5	-.20	0.88
5	-.10	1.75
5	.30	-0.46
5	.20	-1.01
5	.10	-0.06
5	.30	-0.02
5	.20	0.11
5	.10	-0.38
5	.30	-0.12
5	.20	0.67
5	.10	0.06
9	-.30	-0.29
9	-.20	-0.14
9	-.10	-0.15
9	-.30	-0.48
9	-.20	-0.61
9	-.10	-0.44
9	-.30	1.18

Color Patch	Density Variations	Delta Hue Reading
9	-.20	0.93
9	-.10	0.48
9	.30	-0.20
9	.20	-0.32
9	.10	-0.17
9	.30	0.61
9	.20	0.40
9	.10	-0.27
9	.30	-0.77
9	.20	-0.09
9	.10	-0.56
13	-.30	-0.43
13	-.20	-0.31
13	-.10	-0.40
13	-.30	-0.78
13	-.20	-0.18
13	-.10	-0.03
13	-.30	2.03
13	-.20	1.07
13	-.10	0.77
13	.30	-0.22
13	.20	-0.78
13	.10	0.29
13	.30	-0.03
13	.20	0.06
13	.10	-0.50
13	.30	-1.23
13	.20	-0.54
13	.10	-0.07
17	-.30	3.45
17	-.20	0.37
17	-.10	0.77
17	-.30	0.22
17	-.20	0.84
17	-.10	0.70
17	-.30	3.56
17	-.20	2.36
17	-.10	1.37
17	.30	1.85
17	.20	1.44
17	.10	1.38
17	.30	2.77
17	.20	3.54
17	.10	2.16
17	.30	0.69
17	.20	-1.43
17	.10	1.97
21	-.30	5.95
21	-.20	4.57

Color Patch	Density Variations	Delta Hue Reading
21	-.10	3.44
21	-.30	-0.22
21	-.20	0.31
21	-.10	1.32
21	-.30	3.32
21	-.20	3.27
21	-.10	2.82
21	.30	2.37
21	.20	1.52
21	.10	1.40
21	.30	4.44
21	.20	4.32
21	.10	2.63
21	.30	2.81
21	.20	1.95
21	.10	3.58

Table 4. Data obtained from variations of yellow, magenta, and cyan ink for the A process, process/overprint color grouping.

Color Patch	Density Variations	Delta Hue Reading
4	-.30	-20.01
4	-.20	-14.98
4	-.10	-8.39
4	-.30	-0.96
4	-.20	-2.31
4	-.10	-1.73
4	-.30	17.92
4	-.20	14.75
4	-.10	10.71
4	.30	4.23
4	.20	4.70
4	.10	1.76
4	.30	-1.33
4	.20	-0.86
4	.10	0.09
4	.30	-4.92
4	.20	-11.15
4	.10	-3.19
7	-.30	3.79
7	-.20	2.69
7	-.10	1.72
7	-.30	10.74
7	-.20	8.38
7	-.10	5.78
7	-.30	-18.35
7	-.20	-14.70
7	-.10	-10.50
7	.30	-0.94
7	.20	0.13
7	.10	-1.37
7	.30	-1.66
7	.20	-2.16
7	.10	-0.41
7	.30	2.56
7	.20	3.32
7	.10	0.59
8	-.30	-13.89
8	-.20	-8.46
8	-.10	-4.63
8	-.30	0.58
8	-.20	-0.66
8	-.10	0.35

Color Patch	Density Variations	Delta Hue Reading
8	-.30	10.56
8	-.20	9.13
8	-.10	5.16
8	.30	6.47
8	.20	6.61
8	.10	2.89
8	.30	2.29
8	.20	1.44
8	.10	2.51
8	.30	-0.44
8	.20	-7.04
8	.10	-2.40
15	-.30	-0.74
15	-.20	0.20
15	-.10	1.14
15	-.30	8.86
15	-.20	7.81
15	-.10	5.07
15	-.30	-15.69
15	-.20	-8.12
15	-.10	-4.84
15	.30	7.05
15	.20	6.10
15	.10	2.41
15	.30	1.60
15	.20	0.49
15	.10	3.73
15	.30	5.98
15	.20	5.71
15	.10	2.33
16	-.30	22.12
16	-.20	12.59
16	-.10	5.21
16	-.30	-9.29
16	-.20	-7.17
16	-.10	-4.70
16	-.30	1.01
16	-.20	-0.14
16	-.10	-0.08
16	.30	-6.08
16	.20	-5.40
16	.10	-1.22
16	.30	2.27
16	.20	3.84
16	.10	-0.87
16	.30	-0.22
16	.20	10.12
16	.10	0.41
19	-.30	4.39

Color Patch	Density Variations	Delta Hue Reading
19	-.20	2.11
19	-.10	-0.75
19	-.30	-6.94
19	-.20	-4.89
19	-.10	3.15
19	-.30	2.58
19	-.20	1.48
19	-.10	2.69
19	.30	-6.16
19	.20	-5.88
19	.10	-6.17
19	.30	-3.86
19	.20	-2.95
19	.10	-2.06
19	.30	-4.57
19	.20	2.13
19	.10	-3.61

Table 5. Data obtained from variations of yellow, magenta, and cyan ink for the B process, process/overprint color grouping.

Color Patch	Density Variations	Delta Hue Reading
4	-.30	-16.01
4	-.20	-10.94
4	-.10	-7.06
4	-.30	-1.90
4	-.20	2.75
4	-.10	-2.37
4	-.30	11.11
4	-.20	8.34
4	-.10	6.47
4	.30	3.03
4	.20	3.42
4	.10	1.38
4	.30	-1.54
4	.20	-1.96
4	.10	-1.45
4	.30	-4.86
4	.20	-9.74
4	.10	-2.00
7	-.30	2.71
7	-.20	3.17
7	-.10	1.63
7	-.30	10.58
7	-.20	7.41
7	-.10	6.40
7	-.30	-15.20
7	-.20	-11.46
7	-.10	-7.77
7	.30	1.13
7	.20	1.09
7	.10	-1.24
7	.30	-1.31
7	.20	-0.56
7	.10	1.42
7	.30	3.76
7	.20	2.71
7	.10	1.85
8	-.30	-13.83
8	-.20	-9.26
8	-.10	-5.74
8	-.30	-0.43
8	-.20	-2.27
8	-.10	-0.27

Color Patch	Density Variations	Delta Hue Reading
8	-.30	10.20
8	-.20	7.22
8	-.10	4.17
8	.30	5.25
8	.20	5.49
8	.10	2.92
8	.30	0.71
8	.20	0.29
8	.10	1.78
8	.30	-1.17
8	.20	-8.19
8	.10	-2.40
15	-.30	-0.75
15	-.20	0.28
15	-.10	0.54
15	-.30	5.59
15	-.20	4.22
15	-.10	2.31
15	-.30	-9.54
15	-.20	-4.61
15	-.10	-4.26
15	.30	2.73
15	.20	2.18
15	.10	0.64
15	.30	-0.07
15	.20	0.05
15	.10	2.19
15	.30	4.28
15	.20	3.64
15	.10	0.67
16	-.30	12.26
16	-.20	6.20
16	-.10	3.45
16	-.30	-4.44
16	-.20	-3.16
16	-.10	-1.84
16	-.30	2.49
16	-.20	0.34
16	-.10	0.02
16	.30	-4.17
16	.20	-3.13
16	.10	-0.47
16	.30	2.72
16	.20	3.35
16	.10	0.08
16	.30	-0.70
16	.20	2.85
16	.10	-0.37
19	-.30	-2.62

Color Patch	Density Variations	Delta Hue Reading
19	-.20	5.46
19	-.10	1.46
19	-.30	0.79
19	-.20	-5.67
19	-.10	-4.61
19	-.30	-3.97
19	-.20	-1.59
19	-.10	-1.98
19	.30	-14.05
19	.20	-7.68
19	.10	-7.28
19	.30	-5.41
19	.20	-2.75
19	.10	-2.79
19	.30	-3.27
19	.20	-4.06
19	.10	2.42

Table 6. Data obtained from variations of yellow, magenta, and cyan ink for the C process, process/overprint color grouping.

Color Patch	Density Variations	Delta Hue Reading
4	-.30	-13.48
4	-.20	-9.79
4	-.10	-9.80
4	-.30	-1.35
4	-.20	-2.20
4	-.10	-1.68
4	-.30	8.47
4	-.20	6.98
4	-.10	5.72
4	.30	3.38
4	.20	3.23
4	.10	0.84
4	.30	-0.40
4	.20	-0.68
4	.10	0.08
4	.30	-2.99
4	.20	-7.71
4	.10	-2.02
7	-.30	1.25
7	-.20	2.38
7	-.10	1.84
7	-.30	10.52
7	-.20	6.65
7	-.10	5.26
7	-.30	-15.09
7	-.20	-11.09
7	-.10	-8.68
7	.30	1.65
7	.20	2.63
7	.10	0.40
7	.30	-1.00
7	.20	-1.30
7	.10	1.42
7	.30	4.15
7	.20	2.86
7	.10	0.42
8	-.30	-10.83
8	-.20	-6.57
8	-.10	-4.02
8	-.30	1.15
8	-.20	0.54
8	-.10	1.67

Color Patch	Density Variations	Delta Hue Reading
8	-.30	10.13
8	-.20	8.96
8	-.10	7.83
8	.30	5.73
8	.20	5.36
8	.10	2.43
8	.30	2.50
8	.20	3.15
8	.10	4.36
8	.30	0.07
8	.20	-5.58
8	.10	-0.84
15	-.30	0.36
15	-.20	0.85
15	-.10	1.26
15	-.30	3.66
15	-.20	3.04
15	-.10	2.01
15	-.30	-7.69
15	-.20	-5.29
15	-.10	-4.68
15	.30	1.54
15	.20	1.35
15	.10	0.87
15	.30	0.18
15	.20	0.40
15	.10	1.85
15	.30	3.90
15	.20	3.73
15	.10	0.58
16	-.30	10.14
16	-.20	5.33
16	-.10	2.81
16	-.30	-2.19
16	-.20	-0.87
16	-.10	0.41
16	-.30	2.26
16	-.20	1.80
16	-.10	0.79
16	.30	-2.25
16	.20	-1.76
16	.10	0.15
16	.30	2.38
16	.20	1.95
16	.10	1.22
16	.30	0.76
16	.20	4.15
16	.10	0.44
19	-.30	6.86

Color Patch	Density Variations	Delta Hue Reading
19	-.20	4.61
19	-.10	2.95
19	-.30	-1.82
19	-.20	-1.36
19	-.10	-1.20
19	-.30	0.92
19	-.20	0.61
19	-.10	-0.58
19	.30	-4.37
19	.20	-4.95
19	.10	-1.48
19	.30	0.32
19	.20	0.45
19	.10	-0.59
19	.30	-0.42
19	.20	5.23
19	.10	-1.11

Table 7. Data obtained from variations of yellow, magenta, and cyan ink for the A process, hard to print color grouping.

Color Patch	Density Variations	Delta Hue Reading
2	-.30	4.84
2	-.20	3.94
2	-.10	2.15
2	-.30	19.79
2	-.20	13.72
2	-.10	9.23
2	-.30	-26.59
2	-.20	-22.70
2	-.10	-18.62
2	.30	-4.19
2	.20	-2.73
2	.10	-0.34
2	.30	-3.20
2	.20	-3.88
2	.10	-2.08
2	.30	4.30
2	.20	5.99
2	.10	0.05
6	-.30	28.96
6	-.20	17.76
6	-.10	11.34
6	-.30	-20.10
6	-.20	-14.21
6	-.10	-8.96
6	-.30	0.01
6	-.20	-0.34
6	-.10	-1.87
6	.30	-9.75
6	.20	-10.02
6	.10	-1.94
6	.30	1.51
6	.20	4.65
6	.10	-2.20
6	.30	-0.61
6	.20	7.31
6	.10	-0.81
10	-.30	-24.85
10	-.20	-18.04
10	-.10	-10.02
10	-.30	-0.77
10	-.20	-1.58
10	-.10	-1.29

Color Patch	Density Variations	Delta Hue Reading
10	-.30	19.68
10	-.20	14.93
10	-.10	8.85
10	.30	7.81
10	.20	7.80
10	.10	2.44
10	.30	-2.30
10	.20	-2.67
10	.10	-1.83
10	.30	-5.57
10	.20	-13.91
10	.10	-0.95
14	-.30	-6.41
14	-.20	-2.90
14	-.10	-2.68
14	-.30	-0.83
14	-.20	-2.17
14	-.10	-96.00
14	-.30	2.67
14	-.20	1.96
14	-.10	0.22
14	.30	-0.71
14	.20	-1.10
14	.10	-1.22
14	.30	-0.81
14	.20	-1.18
14	.10	-1.16
14	.30	-2.54
14	.20	-4.04
14	.10	-3.79
18	-.30	-3.58
18	-.20	-2.16
18	-.10	-0.20
18	-.30	2.35
18	-.20	1.77
18	-.10	1.15
18	-.30	-1.04
18	-.20	-0.47
18	-.10	-0.97
18	.30	4.12
18	.20	3.70
18	.10	2.76
18	.30	1.36
18	.20	1.26
18	.10	1.46
18	.30	2.51
18	.20	0.37
18	.10	0.42
22	-.30	9.60

Color Patch	Density Variations	Delta Hue Reading
22	-.20	5.69
22	-.10	4.13
22	-.30	-0.74
22	-.20	-0.68
22	-.10	-0.22
22	-.30	-5.70
22	-.20	-4.29
22	-.10	-2.95
22	.30	-7.66
22	.20	-8.08
22	.10	-3.30
22	.30	-0.11
22	.20	-0.36
22	.10	-0.25
22	.30	1.97
22	.20	3.91
22	.10	1.37

Table 8. Data obtained from variations of yellow, magenta, and cyan ink for the B process, hard to print color grouping.

Color Patch	Density Variations	Delta Hue Reading
2	-.30	3.09
2	-.20	2.14
2	-.10	1.01
2	-.30	15.61
2	-.20	11.38
2	-.10	8.30
2	-.30	-21.06
2	-.20	-17.07
2	-.10	-14.18
2	.30	-0.25
2	.20	0.49
2	.10	1.01
2	.30	-1.34
2	.20	-1.96
2	.10	0.99
2	.30	4.69
2	.20	4.36
2	.10	1.00
6	-.30	24.26
6	-.20	15.09
6	-.10	10.70
6	-.30	-15.65
6	-.20	-10.02
6	-.10	-6.59
6	-.30	1.96
6	-.20	0.21
6	-.10	-0.36
6	.30	-7.73
6	.20	-6.92
6	.10	3.97
6	.30	4.05
6	.20	-1.06
6	.10	0.89
6	.30	8.03
6	.20	0.19
6	.10	-1.43
10	-.30	-23.04
10	-.20	-16.38
10	-.10	-9.76
10	-.30	-0.89
10	-.20	-1.64
10	-.10	-1.74

Color Patch	Density Variations	Delta Hue Reading
10	-.30	17.90
10	-.20	12.96
10	-.10	8.98
10	.30	6.41
10	.20	6.29
10	.10	1.94
10	.30	-2.19
10	.20	-2.09
10	.10	-2.11
10	.30	-5.81
10	.20	-14.36
10	.10	-0.44
14	-.30	-5.02
14	-.20	-2.71
14	-.10	-1.90
14	-.30	-0.56
14	-.20	-1.66
14	-.10	-0.44
14	-.30	3.42
14	-.20	2.18
14	-.10	0.94
14	.30	-0.59
14	.20	-0.14
14	.10	-1.16
14	.30	-0.60
14	.20	-0.41
14	.10	-0.28
14	.30	-1.83
14	.20	-3.89
14	.10	-3.06
18	-.30	-3.72
18	-.20	-2.08
18	-.10	-1.41
18	-.30	0.42
18	-.20	0.05
18	-.10	0.01
18	-.30	-1.40
18	-.20	-0.89
18	-.10	-0.43
18	.30	1.80
18	.20	2.09
18	.10	1.21
18	.30	-0.47
18	.20	-0.41
18	.10	0.02
18	.30	1.04
18	.20	0.03
18	.10	-0.50
22	-.30	4.39

Color Patch	Density Variations	Delta Hue Reading
22	-.20	3.13
22	-.10	1.76
22	-.30	-1.53
22	-.20	-1.30
22	-.10	-0.24
22	-.30	-3.23
22	-.20	-2.62
22	-.10	-1.51
22	.30	-3.29
22	.20	-3.75
22	.10	-1.94
22	.30	-0.45
22	.20	-0.23
22	.10	-0.37
22	.30	0.81
22	.20	2.05
22	.10	-0.09

Table 9. Data obtained from variations of yellow, magenta, and cyan ink for the C process, hard to print color grouping.

Color Patch	Density Variations	Delta Hue Reading
2	-.30	2.08
2	-.20	2.25
2	-.10	0.66
2	-.30	14.14
2	-.20	9.90
2	-.10	8.16
2	-.30	-18.22
2	-.20	-13.63
2	-.10	-11.94
2	.30	1.37
2	.20	2.35
2	.10	1.22
2	.30	0.03
2	.20	-0.33
2	.10	0.93
2	.30	4.35
2	.20	2.99
2	.10	1.58
6	-.30	23.77
6	-.20	14.35
6	-.10	9.49
6	-.30	-14.20
6	-.20	-9.64
6	-.10	-5.78
6	-.30	1.40
6	-.20	-0.92
6	-.10	-0.69
6	.30	-8.04
6	.20	-8.66
6	.10	-1.00
6	.30	2.75
6	.20	2.56
6	.10	-1.78
6	.30	-0.65
6	.20	7.44
6	.10	-1.42
10	-.30	-22.59
10	-.20	-17.09
10	-.10	-10.10
10	-.30	-1.83
10	-.20	-2.15
10	-.10	-1.55

Color Patch	Density Variations	Delta Hue Reading
10	-.30	15.63
10	-.20	11.88
10	-.10	8.36
10	.30	6.32
10	.20	6.71
10	.10	2.03
10	.30	-2.32
10	.20	-2.74
10	.10	-2.63
10	.30	-6.07
10	.20	-13.60
10	.10	-1.89
14	-.30	-5.48
14	-.20	-2.77
14	-.10	-1.44
14	-.30	-0.79
14	-.20	-1.10
14	-.10	-0.12
14	-.30	3.09
14	-.20	2.55
14	-.10	1.74
14	.30	-0.47
14	.20	-0.77
14	.10	-1.06
14	.30	-0.04
14	.20	-0.25
14	.10	-0.19
14	.30	-2.15
14	.20	-3.50
14	.10	-2.53
18	-.30	-3.00
18	-.20	-1.71
18	-.10	-0.71
18	-.30	1.36
18	-.20	0.89
18	-.10	0.95
18	-.30	-1.18
18	-.20	-0.42
18	-.10	-0.05
18	.30	2.81
18	.20	3.38
18	.10	1.50
18	.30	0.78
18	.20	0.60
18	.10	1.09
18	.30	2.01
18	.20	0.20
18	.10	0.14
22	-.30	1.53

Color Patch	Density Variations	Delta Hue Reading
22	-.20	1.37
22	-.10	1.05
22	-.30	0.14
22	-.20	-0.06
22	-.10	0.17
22	-.30	-1.07
22	-.20	-0.56
22	-.10	-0.54
22	.30	-0.25
22	.20	-0.06
22	.10	0.38
22	.30	1.04
22	.20	0.83
22	.10	0.34
22	.30	0.91
22	.20	0.95
22	.10	0.38