Extended Color Gamut for Flexographic Printing

Sheth G.D[1]. , Lovell V.[2], Pekarovicova A.[1], Fleming P.D.[1]

[1]Western Michigan University, Department of Paper Engineering, Chemical Engineering and Imaging, Center for Ink and Printability, 4601 Campus Dr., A - 231 Parkview, Kalamazoo, MI 49008-gaurav.d.sheth@wmich.edu

[2]Sun Chemical Corporation, Color Research Lab, 1701 Westinghouse Blvd, Charlotte, NC 28273; veronika.lovell@sunchemical.com

Keywords: flexography, extended gamut, printing order

Abstract

The advancement in technology and the necessity to satisfy the increasing quality requirements has aroused the need for use of extended color gamut in flexographic printing. The information about extended gamut inks and ink systems is not easily available, therefore it is essential to find ink sets and color sequences that will produce optimal results in the flexographic printing process. The project includes the study of water based single-pigmented and dual pigmented ink sets used to develop extended color gamut. A test chart was created with the process color inks and three additional inks – Orange, Violet and Green with the help of ProfileMaker 5.0.8. The test chart was printed on an AL20L3 Mark Andy flexographic press on a semigloss litho substrate. Multiple press setups and various ink sequences were used in order to understand the nature and performance of these specially designed water based color ink sets. The transparency/opacity of the inks and trapping of the single and two pigmented inks were studied in relation to color gamut development. In addition, the print sequence effects on overprinting spot color and color gamut were studied. It was observed that the ultimate performance of the inks is dependent on many of the studied factors. The transparency, opacity and color properties of the inks can dictate the most appropriate ink sequence, which can then lead to even larger enhancement of the color gamut of a specified ink set. The use of different ink systems like mono and dual pigmented; offer various advantages, such as coverage of unusual areas of the color space and better control of the ink hues. Different ink sequences can lead to huge enhancement in the measured color gamut, which in this case was provided by the YOMGCVK (Yellow-Orange-Magenta-Green-

Cyan-Violet-Black) print sequence. The transparency and opacity play a key role in the outcome of the gamut. The chroma values calculated from the overprint of the different ink sequences printed on K-proofer confirmed that certain ink sequences produce higher color saturation as compared to their counterparts.

Introduction

Flexography is competing with lithography and gravure to produce better quality products. The significance of flexographic printing can be stated due to following factors: versatility, speed of production, lower cost, and reduced environmental impact (Anon, 1998; Kendra, 1997). Color is one of the most critical components in determining print quality. It is a fact that the CMYK color space is considerably smaller than the color space that is visible to the human eye. It has limitations in four-color process printing where applications in which color matching is critical are involved. Violets, greens and oranges are typically very difficult to match using 4-color process (Pekarovicova, 2008). The basic principle of extended gamut is the addition of two or three inks to the conventional CMYK to enable printing a wider range of colors with intense, highly saturated effects. It also enables the reproduction of 90 percent of the colors from the Pantone Color Matching System as compared to the process color inks that can reproduce only 60 percent of the colors of the Pantone color system. There are many advantages of extended color gamut, such as less color correction on press, consistent and predictable color with excellent sharpness, exceptional detail with superb contrast and brightness, great efficiency on the press (Chen, et al., 2004). It also offers color-critical solutions to high impact graphics through the work in prepress and creates larger number of printable colors (Chen, et al., 2004; Hulsman, 2000). The technology is well suited to high-end printing applications; the small dots reproduce the detailed images very accurately, maintaining the exact hue and saturation of the printed image. Along with optimized press conditions, extended color gamut is a result of excellent prepress conditions with respect to proofing technology, color separation and the proper toolset to create reproducible press ready files. It is possible to produce exceptional printed results more effectively by the use of extended gamut as compared to use of only spot colors. The availability of a larger color space and accurate proofing techniques, the prepress can make spot colors that are very close to the required color for printing with the least bit of error. Also with the help of standardized ink sets and anilox rollers, color accuracy can be optimized with excellent color density (Dalal, 2012; Wyszecki, et al., 1982). Extending color gamut is not a new concept, but the process is mostly proprietary, thus lack of information about the inks and ink systems makes it is essential to find ink sets and color sequences that will produce optimal results in the flexographic printing process.

Experimental

The research work was divided into several different tasks, which were as follows:

- Creation of test charts with spot color overprints in ProfileMaker 5.0.8 software environment.

- Flexographic press run of test chart with YMCK and YMCK GOV inks, with different print sequence of colors.

- Calculation of Chroma of overprints.

- Measuring and calculating the printed ink film opacity.

- Development of correlation equation for opacity calculated from reflectance and opacity calculated from transmission.

A special test chart was designed for this project in the environment of ProfileMaker Pro 5.0.8. Numerous overprints of process colors as well as spot colors were printed using the flexographic printing process. Inks used were water based spot color inks Orange, Violet and Green with flexographic process color inks cyan, magenta, yellow and black. The print run was done on coated semi-gloss litho label stock, and its physical properties are given in Table 1.

Property	Semi-Gloss Litho (One side coated)
Roughness [µm]	1.52
PPS Porosity [mL/min]	5.64
Brightness [%GE]	84.4
Specular gloss at 75° [%]	60.5
Caliper [µm]	145

Table 1: *Physical properties of the substrate*

The roughness of the substrates was measured by Parker Print Surf (PPS) instrument using soft backing and 500 kPa clamping pressure. PPS Porosity was also measured on Parker Print Surf instrument with 500 kPa clamping pressure. Specular gloss was measured at 75-degree geometry using the ProfilePlus Technidyne instrument. Caliper was measured using the ProfilePlus Technidyne instrument. Brightness was measured using a Technidyne Brightimeter Micro S-5. The Semi-gloss Litho substrate was backed with release liner.

Print Trials

An eight -station AL20L3 Mark Andy 2200 flexographic 10 inch label press with a BST Pro Mark registration system equipped with a Power Scope 3000 video camera (Pro Mark Edition) was employed for printing. The press speed was 200 fpm. Inks were printed in order YMCK, YMCK+ OGV with two different OGV ink sets, and YOMGCVK with two different OGV ink sets. As shown in Table 2, different ink sets included single pigmented orange, green and violet, and the other a two-pigmented OGV set. A screen ruling of 150 lpi was set for the .067 DFQ flexographic plates, with screen angles for cyan 7.5°; magenta 67.5°; yellow 82.5°; black 37.5°, orange 7.5°, violet 82.5° and green 67.5° to avoid the moiré effect. Black and magenta stations were equipped with 800 lpi anilox rollers with 2.8 BCM cell volume, the rest of the stations had anilox rollers with 600 lpi resolution and 3.8 BCM cell volume. After printing, CIELAB values of the single color and overprint patches were measured using MeasureTool 5.0.8, profiles were made in ProfileMaker 5.0.8 and the color gamut volumes were determined in ColorThink 3.0 Pro and ProfileEditor 5.0.8 software for comparison.

Run	Substrate	Ink Sequence
1B	Semigloss Litho	YMCK
2B	Semigloss Litho	YMCK OGV (single pigmented inks)
3B	Semigloss Litho	YMCK O2G2V2 (two pigmented inks)
4B	Semigloss Litho	YO2MG2CV2K (two pigmented inks)
5B	Semigloss Litho	YOMGCVK (single pigmented inks)

Table 2: *Press Trial*

Test Charts

In order to understand and clarify the abilities of extended color gamut printing, a special test chart was created using ProfileMaker 5.0.8. The test charts, as shown in Figure 1, shows the target with a total of 1560 patches for the CMYKOGV chart and 1798 patches for the CMYK chart. CMYKOGV chart was specially designed to constitute the process colors as well as the additional colors, orange, violet and green. As the test chart had three additional color channels, in addition to the process colors, it had a tone values from 0-100 %, i.e. tints in a 10 % increment for each color. Along with these tone values, it also contains different overprints of different intensity from highlights to shadows of solids and halftones of one, two and three and up to 400% total coverage area.

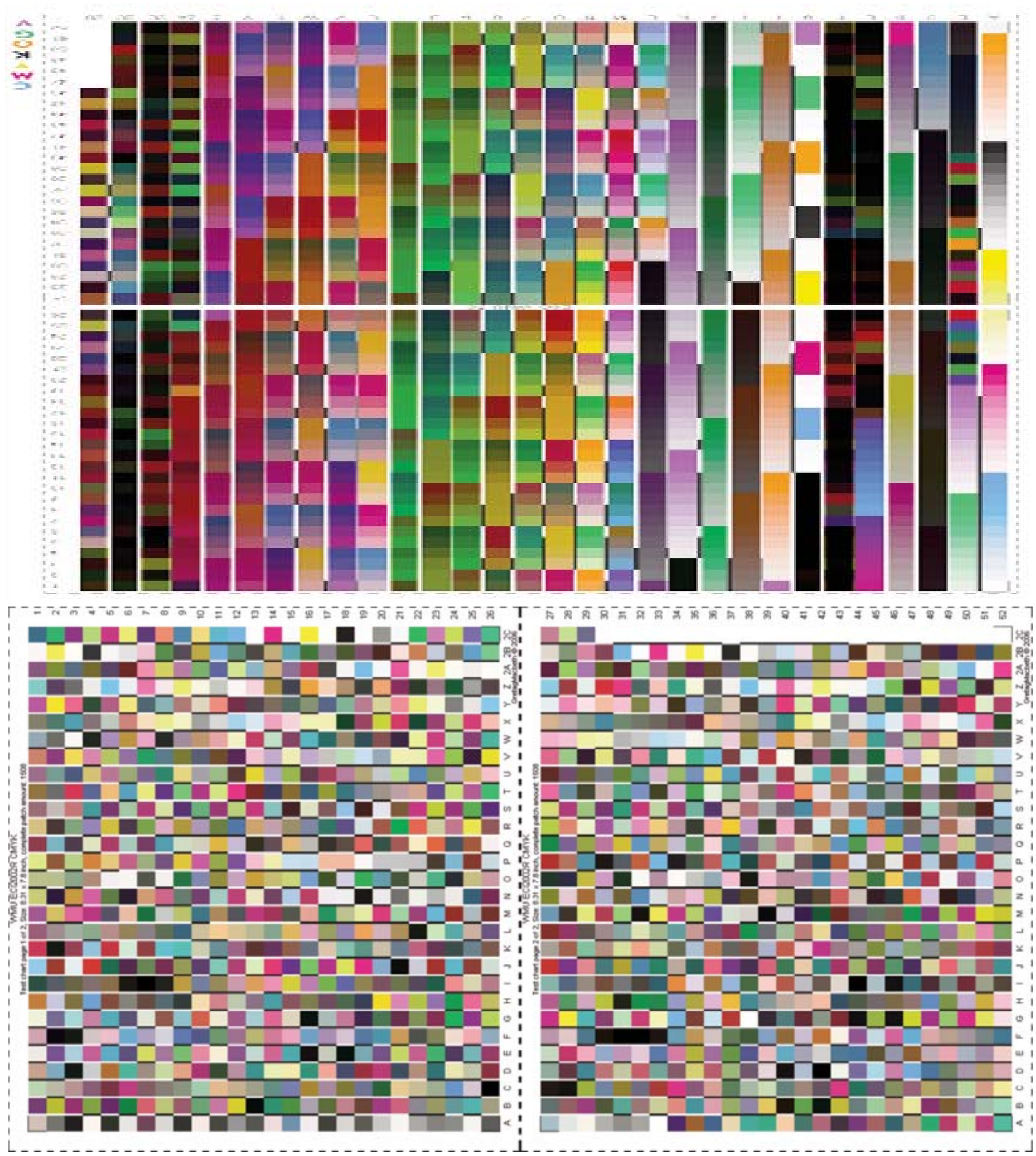

Figure 1: *Test Chart with 7 channels, YMCK + OGV (Top) and ECI 2002R (CMYK) chart (Bottom)*

Opacity Calculation

Opacity was calculated by taking into account the ratio of selected tristimulus values (X, Y and Z) for particular colored ink, and overprints of selected ink combinations from black and white area of the Leneta chart. For the calculation of overprinting opacity due to the order of inks, ink drawdowns of two ink overprints were performed. Two inks were overprinted using the K-proofer in flexo mode on PET substrate as well as Leneta charts. A tone step patterned flexographic plate was used with tone steps of 25%, 50%, 75% and 100%.

$$\text{Opacity of Ink (\%)} = (RB/RW) \times 100 \quad \text{(Equation 1)}$$

Where
Rb is respective reflectance value from black area
Rw is respective reflectance value from white area

Calculation of Chroma

Most color space models define color in three dimensions and provide a scheme for representing color in terms of three coordinates. These color models include hue, saturation and value and also luminance, chroma and hue. Chroma is the colorfulness of the particular color. For the research of chroma effect on color gamut, the chroma for different ink overprints was calculated from the printed sheets of different ink sequences. Changing the ink sequences gives different chroma results, which are corroborated to study which sequence produces the highest color gamut. The printed sheets were measured by using Measure Tool, an i1/iO spectrophotometer and compared.

The formula used to calculate chroma can be stated (Lubbe, 2010) as follows:


(Equation 2)

Where
C_{ab}*is the Chroma
a* and b* are the redness/greenness and yellowness/blueness values of CIELAB system

Results and Discussion

Gamut Volume

The color gamut is the range of colors that can be printed using a particular media, ink, or process. Mathematically, the color gamut volume, a volume in CIELAB space, is the number of colors that are discernable within a ΔE tolerance of $\sqrt{3}$ (Lovell, 2009). The monitor has a larger color gamut than the YMCK printed job and thus rendering intents are used to deal with out-of-gamut colors (Hrehorova, 2006). Printed patches were measured in CIELAB color space and profiles were created using ProfileMaker 5.0.8. Profile inspector CHROMiX ColorThink 3.0 Pro was used to calculate the gamut volumes of the profiles, which were then plotted (Figure 2).

The color gamut of YMCK print on Semi-Gloss Litho substrate was 401,000. The seven-color print of YMCKOGV with mono pigmented OGV inks resulted in 28% increased color gamut. The recorded value of color gamut for YMCKOGV was 512,000 CCU. YMCKO2G2V2 recorded a color gamut volume of 499,000, which related to 25% increase against the four-color gamut volume. The change of color sequence order from YMCKOGV to YOMGCVK resulted in further color gamut

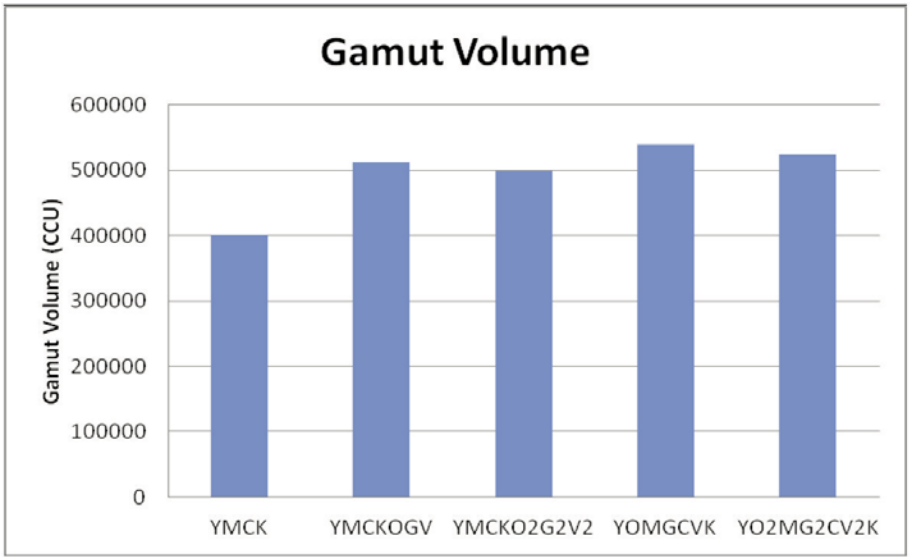

Figure 2: *Gamut volume of YMCK and YMCKOGV flexo prints with single and dual pigmented inks*

increase by 34% with a value of 539,000. The 34% increase was for single pigmented inks, moreover there was a 30% increase for spot color OVG inks with a recorded value of 524,000. The change of print sequence to YOMGCVK was done based on the calculated transparency of the respective inks.

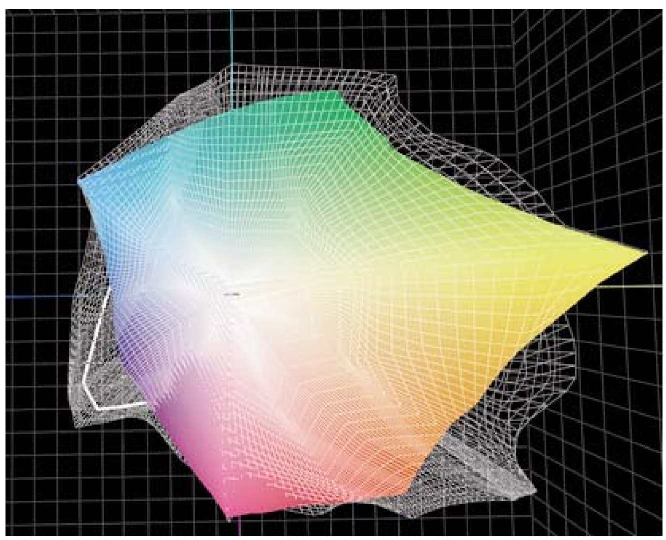

Figure 3: *Comparison of YMCK color gamut (Colored) to YOMCGVK gamut (Wire Frame) of single pigmented inks*

It was found that the set of single pigmented OGV inks provided better result for color gamut as compared to the two-pigmented OGV inks. The gamut for YOMGCVK (single color) was the largest gamut recorded. Considering the ECG situation alone, it was observed that the change of color sequence for single pigmented inks results in 5.2% increase in color gamut, and 4.9% increase for two-pigmented OGV inks.

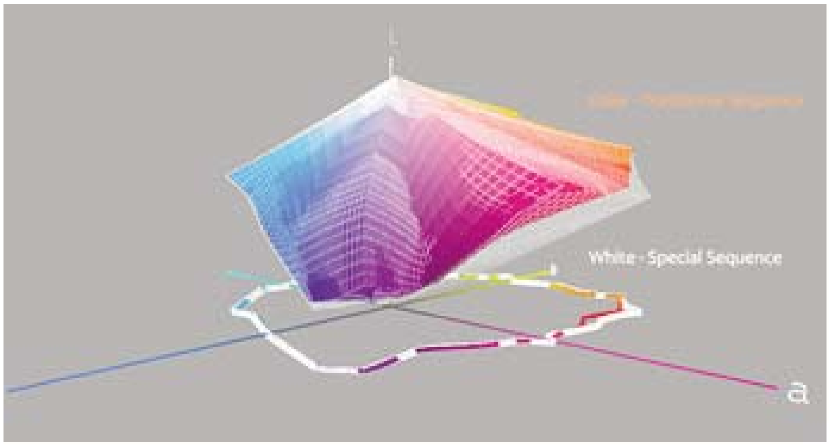

Figure 4: *Comparison of color gamut of YOMCGVK (Wireframe) and YMCKOGV sequence (Color) of single pigmented inks*

The most significant difference in color gamut was recorded between the four-color print and seven-color print with the use of single pigmented inks and by applying a special print sequence. The prime increase in the color gamut was obtained by contribution of the green, orange and violet inks. Single pigmented inks delivered a larger color gamut than two pigmented inks.

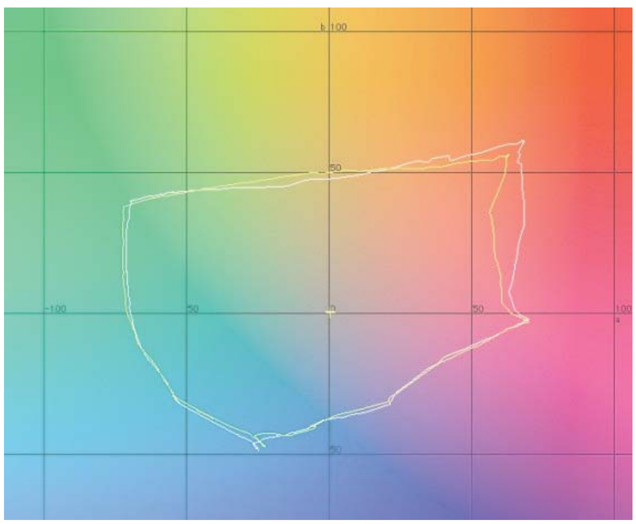

Figure 5: *2-D Projection of YOMCGVK (white) and YMCKOGV sequence (yellow) for single pigmented inks*

Comparing YMCKOGV print order to YOMGCVK, it is observed that the increase of gamut is seen mainly in the magenta-red- orange-yellow area for single pigmented ink system. Changing the order from YMCKO2G2V2 to YO2MG2CV2K for two pigmented ink system produces a gamut increase in yellow-orange-red and yellow-green area. The increase in color gamut is most likely associated with overprinting order, which is associated with trapping of the colors, their opacity or transparency, and chroma of the overprints. Therefore, the attention was oriented towards examining of overprints of the colors and their opacity and color properties.

Optical Properties of Ink Sets

In order to better understand the behavior of inks and their overprints, drawdowns of inks and their combinations in different order was made (see Experimental). Opacity was calculated from respective XYZ values according to Equation (1), and the values are illustrated in the Figure 6.

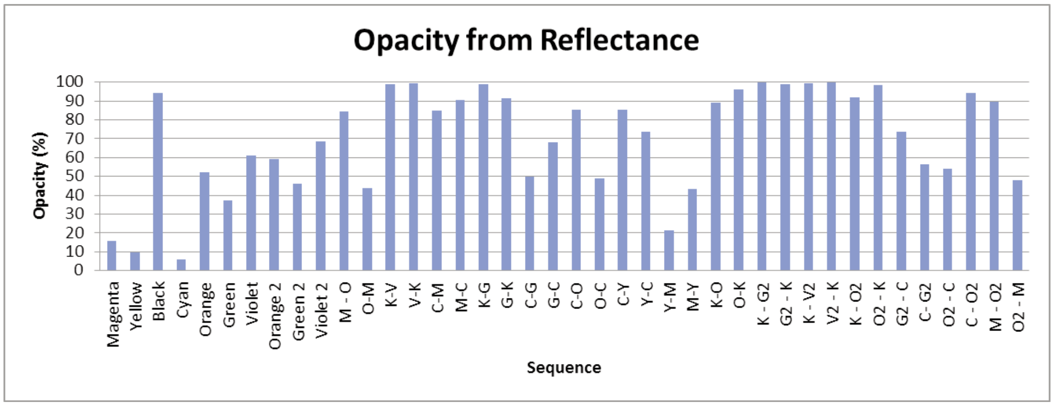

Figure 6: *Opacity of single inks and overprints of two inks.*

The opacity of overprints involving black and violets is close to 100% and in any order they are almost equal. Magenta printed over orange has lower opacity as compared to orange printed over magenta, and it was true for both single and dual pigmented orange inks, OC was less opaque than CO for single and dual pigmented orange ink. Similarly, green over cyan has lower opacity as compared to cyan over green. Also, cyan over yellow is less opaque in comparison to printing yellow over cyan. Thus, it is very important to consider the order of inks in order to achieve highest transparencies, or lowest opacities. In this experiment it was confirmed that certain print sequences produce higher opacities when compared with the combination of the same inks in reversed order.

Opacities of dual pigmented (G2, V2, O2) inks are significantly higher than that of single pigmented inks. The interaction of light with the dual pigments gives more opaque prints, but the dual pigments suppress chroma, affecting the color gamut. This plays a key role in the outcome of overall color gamut of a seven-color ink set.

Calculation of Chroma

The chroma values of different variations of printing order were recorded. It was found that single pigmented inks used for YOMCGVK sequence being of the highest values for most overprints. The overprint of orange over yellow for single pigmented ink recorded a chroma that has the highest value as compared to the value of the same print order of dual pigmented ink. Overprints of violets also yielded a higher value with single pigmented inks compared to dual pigmented ones. Similarly, the chroma value recorded for overprint of cyan over magenta was lower as compared the values obtained for cyan over yellow for single pigmented ink. Overprints of orange, green and violet had highest values for YOMGCVK print order as compared to all other printing sequences. The printing order of YOMGCVK with single pigmented ink has the highest values of chroma for most overprints and the values for other overprints that are not the highest are very close to the maximum value obtained. Thus, it can be stated that YOMGCVK with single pigmented ink is the better print order, which can yield the best results for ECG printing.

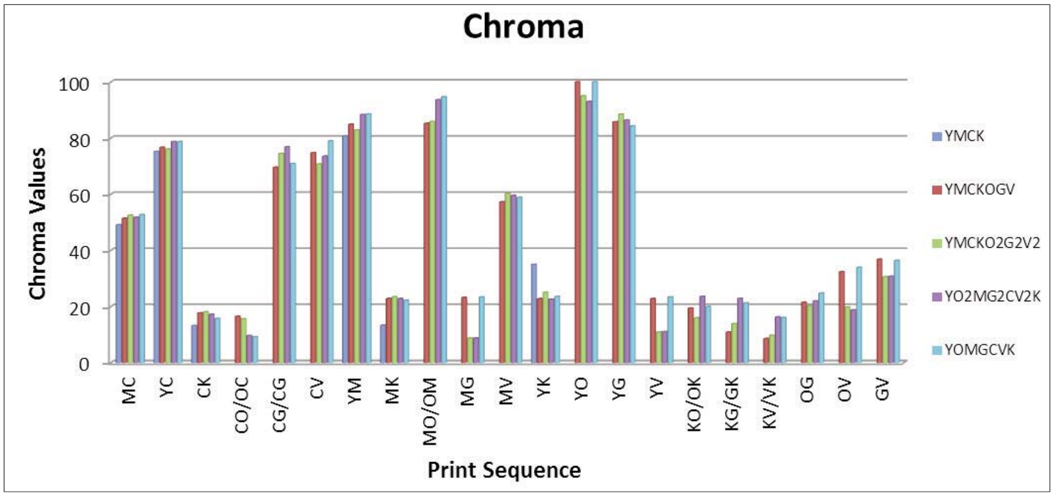

Figure 7: *Chroma values calculated from printed sheets*

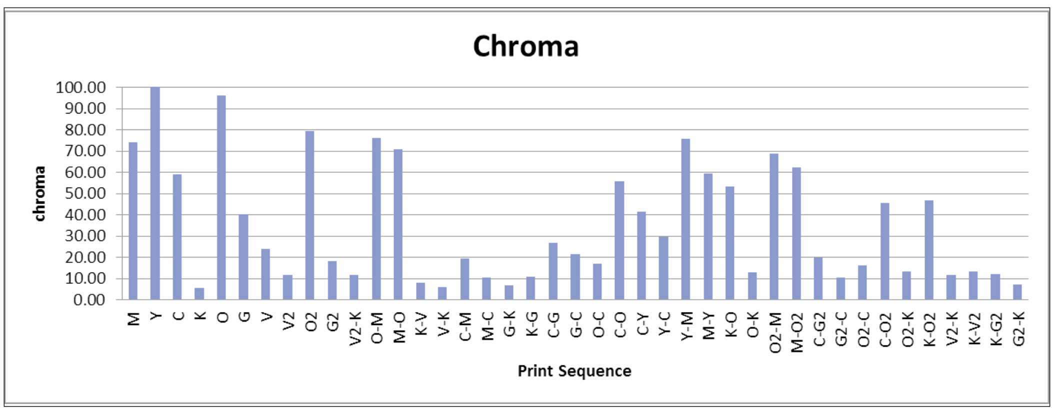

Figure 8: *Chroma values calculated from K-proofer prints*

Chroma values recorded from single print overprints are significantly higher than chroma values of dual pigmented inks. Chroma values involving black inks are very close to zero, which corroborates the definition of black being a no chroma color. The chroma values involving yellow and orange inks records a high value. The chroma values of dual pigmented magenta over orange, green over cyan have relatively lower chroma values as compared to that of single pigmented inks. The print order that produced the highest color gamut was YOMGCVK (yellow, orange, magenta, green, cyan, violet and black); the print sequences of orange over yellow, magenta over orange etc. produce higher chroma in comparison to yellow over orange, orange over magenta etc. Thus, it is safe to say that a change in print order from YMCKOGV to YOMGCVK produces better color gamut.

Conclusion

The main aim of this research work was to evaluate the volume of color gamut of the for different ink sequences of mono pigmented and dual pigmented ink sets and to confirm, that the gamut volume is affected by print order, which created the hypothesis, that the ink combination, producing more transparent composite ink film, will also be more transparent, and will have higher chroma. Changing the print sequences has a significant impact on the color gamut. It is obvious that the color gamut is much larger when additional colors viz. orange, green and violet are used with the process colors. Furthermore, mono pigmented ink sets enlarge the color gamut to a larger extent in comparison to the dual pigmented ink sets.

The chroma values of single O, G, V ink drawdowns were higher than those of dual pigmented O2, G2, and V2. Also, the overprints of two inks involving single pigmented OGV had higher chroma than overprints involving dual pigmented O2V2 and G2, and the order of prints affected the chroma values. (e.g. chroma OM 76.3; MO 70.8; O2M 69.0, and MO2 62.3 and OC 17.2 CO 57.8; O2C 16.4; CO2 45.7). The chroma values of these overprints actually provided evidence why YOMGCVK order did produce the highest color gamut. Chromas of different ink overprints were compared by changing print orders. Higher chroma produces more vivid and saturated colors. Combinations of two ink overprints were tested in two possible orders and it was found that the sequence is very important, and it affects the chroma.

Changing the print sequence of ink from the traditional YMCKOGV to YOMGCVK has an auxiliary effect on the color gamut enhancing it further. The extension in color gamut is attributed to ink trapping and ink transparencies, and chroma being also dependent on order of overprinting. The ink transparency/opacity affects the amount of light being reflected from the surface, which leads to richer and more saturated colors. The most significant difference in color gamut was recorded between the four-color print and seven-color print with the use of single pigmented inks and by the use of special ink sequence YOMGCVK. Orange, green and violet ink had a significant contributions in the increase in the color gamut. Additionally the increase of color gamut is seen in the red-orange–yellow area for single pigmented ink system. Changing the order from YMCKO2G2V to YO2MG2CV2K for two pigmented ink system produces a gamut increase in yellow- orange-red and yellow- green areas.

Literature Cited

Albers, J.
2006, Interaction of Color. Revised and Expanded Edition, Yale University Press.

Anon
1998, "Flexographic ink: a process approach", - NJ: Foundation of Flexographic Technical Association; - 2nd Edition.

Berns R.
2000, Billmeyer and Saltzman's Principles of Color Technology: Wiley, New York.

Chen Y., Berns R. and Taplin L.
2004, "Extending printing color gamut by optimizing the spectral reflectance of inks" - NY : Society for Imaging Science and Technology ; RIT, Nov 9 - 12.

Chung R. and Hsu F.
2006, "Gravure process color gamut optimization" Proceedings TAGA.

Chung R. and Hsu F.
2001, Gravure process color gamut optimization": Technical Association of the Graphic Arts,. - pp. 333-345.

Fleming P. D. III., and Pekarovicova A.
2012, "Flexographic Process - Western Michigan University, http://www.wmich.edu/pci/flexo.

Hayes, R.
2009 Flexibility and versatility is key to flexo, Flexo Tech, pp 107

Hrehorova E., Sharma A., Fleming P.D.III,
2006, Color Reproduction Studies in RGB and YMCK Workflows using Inkjet Printer, Proceedings of the 58th TAGA Annual Technical Conference, Vancouver, British Columbia, March 2006.[Online]
http://www.wmich.edu/pci/faculty/Publication/fleming/TAGA%202006%20paper_final%20version.pdf

Hulsman, W. J. and Notermans, J.,
2000, Color Management Requirements in Contract Proofing, Proceedings of IS&T's NIP 16, International Conference on Digital Printing Technologies, Vancover, Oct. 15-20,.

Kendra E.
1997 "Flexography" GATFWorld, p. 4-11.

Kipphan H.
2001, Handbook of print media: technologies and production methods, Springer 1st Ed.

Lovell V. and Fleming III, P. D.
2009 “Color Gamut – New Tool in the Pressroom?” TAPPI J, February, p. 4-11.

Lübbe, E.,
2010, Colours in the Mind - Colour Systems in Reality- A formula for colour saturation, ISBN-13 Books On Demand.

O'Connor, Z.
2010, Color harmony revisited, Color Research and Application, Vol. 35, p. 267–273.

Patel S.
2009, "Determining the effect of printing ink sequence for process colors on color gamut and print quality" in Flexography, - NY : RIT Libraries, - p. 47-68.

Pekarovicova A.
2008, "Flexographic Printing Process" - Western Michigan University, - http://www.wmich.edu/pci/pekarovicova/161199.html.

Pekarovicova A, Lovell V. and Fleming P. D.
2012, "Extended Color Gamut for Flexo Printing" Iarigai. Budapest.

Spitzinger, M.
2000, The reproduction of extended gamut colors for flexographic printing: Using the mechanism of the Munsell book of color, Flexographic Technical Association, Flexo, v 25, n 9, 20-34.

Wyszecki, G. and Stiles, W.
1982, Colour Science: Concept and Methods, Quantitative Data and Formulae, Wiley, New York, p. 111,124,136-139.