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Extended Color Gamut for Flexographic Printing

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EXTENDED COLOR GAMUT FOR FLEXOGRAPHIC PRINTING

by

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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 define ink sets and color sequences that will produce optimal results in the flexographic printing process. The results were produced by evaluating color gamut volumes obtained by printing with four color process inks, and additional ink sequences, as well as by evaluating other print parameters that provide evidence in support of the research work. Special focus was oriented towards ink transparency, to support the hypothesis that the ink sequence that provides the highest transparency will also produce the largest color gamut.

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Gaurav Dinesh Sheth

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Chapter I

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 two pigmented ink sets used to develop extended color gamut by printing on several packaging substrates. [1]

A test chart was created with the process color inks and three spot color 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 five different substrates. 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. Characteristics of the ink were evaluated according to the present printing and graphic industry standards. The properties of printed results were measured using ProfileMaker Measure 5.0.8 software and an X-Rite i1/i0 scanning spectrophotometer.

Extended color gamut ink systems broaden the color space on the press beyond the accessible color space created by the process color inks. The final

performance of the ink sets will be dependent on many of the factors involved and all the variables should play a crucial part in the outcome. 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 overprint 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. Control over most of the printability properties can be exercised with the use of different substrate and ink types and better knowledge of the ink behavior on the press. 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 amount of trapping and the overall opacities of the trapped inks determine the amount of light that is reflected. The reflected light in turn affects the CIE L*a*b* values which play a key role in the measurement of the color gamut. The chroma values calculated from the overprint of the different ink sequences indicate that certain ink sequences produce more color saturation as compared to their counterparts. The chroma and saturation produce the finest printing results and provide the greatest color gamut.

Chapter II

Literature Review

The significant reason for the success of flexography is its flexibility to print on many types of substrates viz. flexible films, paper, label stock, corrugated boxes and cartons or cans. Enormous amounts of material, ranging from thin extensible and flexible materials to rough and tough corrugated boards, can be printed by the flexographic method. [2] The use of digital plates facilitates the manufacture of flexographic plates, with excellent sharpness of dot detail, and improves the quality of the printed image. Inline finishing makes the turnaround and set-up time of print much less costly than other processes. Finally, this printing process accommodates a variety of ink chemistries, such as solvent and water- based, or UV and EB curable inks.

Package printing is growing steadily and will be growing steadily in the future. Distribution of the printing is as follows: 40% of packaging jobs are printed by flexography, 30% by offset lithography, 22% by rotogravure and 8% by digital and other printing processes. [3] Significant growth of flexographic markets is projected in film, labels and flexible packaging. The advantage of the flexographic process is definitely its ability to print on a variety of substrates. [4] To keep the packaging segment attractive, colorfulness and saturation of printed colors is a key and it can definitely be improved with the use of spot color, new available technologies, blending of digital and flexographic printing , or employing hybrid presses having different print units.

Spot colors can be printed by using specially formulated spot color inks with single or multiple colorants. An example of such color would be “Coca-Cola red”. A number of spot color libraries, such as I-Vue and Pantone [5]; with a magnitude of custom colors, are available for the spot color printing industry. High opacity is the most desirable trait of the spot color inks. Alternatively it is possible to arrive at a particular color by blending transparent process color inks, because the light needs to pass through all overprinted ink films and then the reflected light forms the final the color sensation. Spot colors have a wide range of applications in commercial as well as packaging industries.

Process Color

There are two color theories that are predominant in printing for reproducing the color. One is the additive color theory based on primary colors of light – red, green and blue. As shown in figure 1, the additive reproduction process mixes various amounts of red, green and blue light to produce other colors. Combination of additive primary colors with other primary colors produces the additive secondary colors cyan, magenta and yellow. Three primary colors produce white when mixed in equal proportion. Computer monitors, television sets and other such devices work on principle of additive color theory. [6] [7] [8] The other theory that is widely used by printers is the subtractive color theory. Additive secondary colors constitute the primaries for subtractive color theory, which is demonstrated in figure 2. When mixed yellow and magenta give red, magenta and cyan give blue, yellow and cyan give green. Printing is done by using these secondary colors and an overlap of these colors produces a full gamut of colored image.

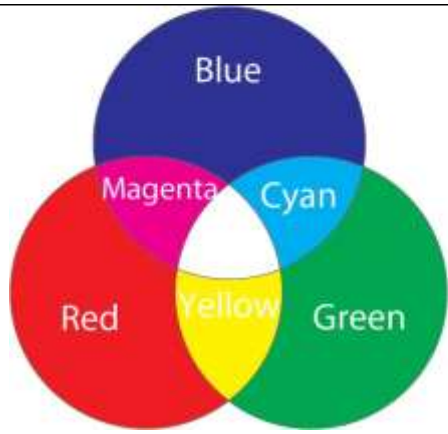	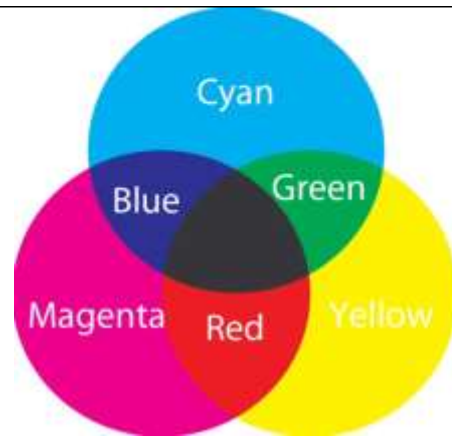
Figure1: Additive Color Theory [9]	Figure2: Subtractive Color Theory [9]

Printing is usually done on a white substrate by using a set of process colors YMCK, additive secondary or subtractive primary colors plus black. [10] [11] [12] To print on to a substrate the full color tone is broken down into halftones by separation of the colors into C – cyan, M – magenta, Y – yellow and K - black. These YMCK tints are called processes colors, and they are printed on paper to reproduce the continuous tone full color image. The separation process breaks down the image into tiny dots that are printed in specific angles on the paper to reproduce the original image. All four colors have different printing angles called as screen angles that can be adjusted. The separations are used to produce four different image carriers or a more common term ‘plates’. These plates are used to print the image, but the image is reproduced with halftone dots and not as a continuous tone image. The dots are very small ranging from 2 to 5 microns in size and to the naked eye give an appearance of a continuous tone image. (13) (14)

Spot Colors

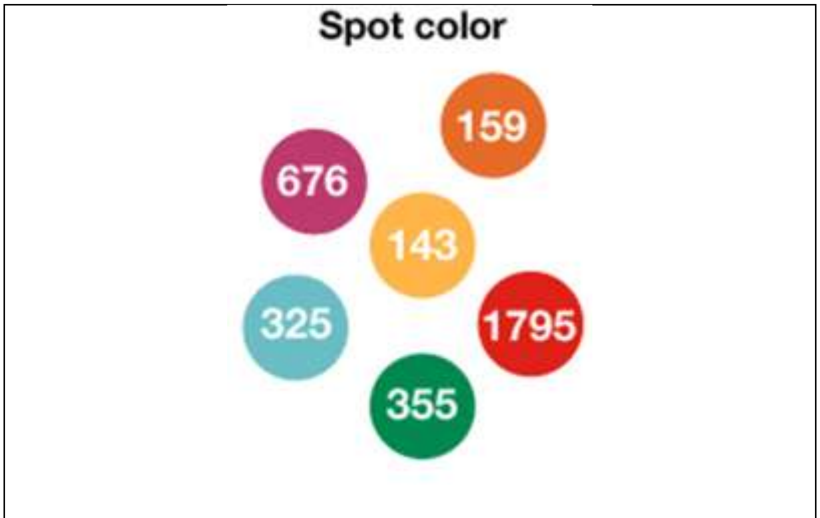

Figure 3: Spot colors from the Pantone color system (15)

A spot color is a single color printed from one printing plate that contains one matched color of ink. They are used for consistent color matching purposes in printing applications where a certain color needs to be reproduced. Spot colors are also termed as special colors and are different from process colors from YMCK. Figure 3 gives a few examples of spot colors from the Pantone color system. They contain premixed colorants and are determined by printed samples or CIELAB values. CIELAB values are accurate in determining the spot color hue, as they are independent of the printing press or printing devices. (16) Spot colors are generally used when the process colors are unable to produce a specific color required by the customer or when the cost of printing with a spot color is lower as compared to process colors. As only a single color is used during printing, it is easier and simpler to maintain consistency and color accuracy of the printed color. Spot colors increase the color gamut of the printing process when used in addition to process colors and allows a wider range of colors giving the printers more control over the color gamut. (17)

Spot Color Inks

Spot color inks are specially colored inks used to achieve a very specific color when printed. Each individual ink is a unique color. The inks are made by a careful combination of pigments mixed in very exact proportions so that the ink maintains its color consistency when laid down on the substrate. Spot color inks are printed on the substrate to represent its color, and its color only, contrasting with process color that uses cyan, magenta, yellow and black inks to print dots on the substrate to create the entire color spectrum.

Special compounds or pigments can be added to the spot color ink to create special effects like metallic gloss or neon glow. These special effects are impossible to attain using four-color process printing. Spot colors are more vibrant than process color inks, have unique color properties and thus are used most frequently to reproduce corporate identity materials. They are typically used for printing of brands of companies such as Coca-Cola, Nike, etc. (19)

Spot Color Overprint

Overprints are obtained by printing colors on top of each other. The process of overprinting is also termed as trapping of colors. Overprinting or trapping can be achieved by printing of process colors or spot colors. Spot color overprints provide a wider color gamut and thus offer more choice of colors that can be obtained with process color. They also give better color uniformity and better control over the consistency of colors. By overprinting spot colors during a press run, a new third color can be obtained. Trapping is an advanced technology and so the designer needs to be very knowledgeable about spot color printing in order to realize expected results. [19] [20] Figure 4 describes the interaction of base ink with the overprinted ink and demonstrates the effects of overprinting.

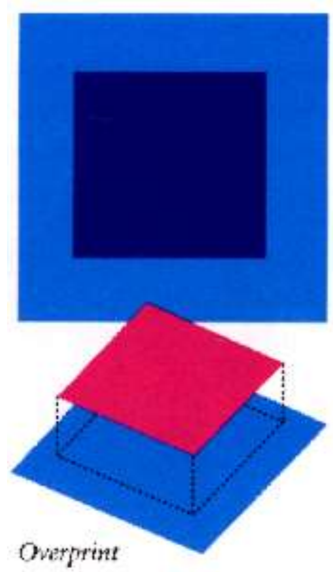

Figure 4: Overprinting of a color [21]

Color Gamut

In color reproduction, the gamut, or color gamut, is a certain complete subset of colors, which is produced by particular set of substrate, inks and print device [22]. The subset of colors can be accurately represented in a given color space or by a certain output device. Digitizing a photograph, converting a digitized image to a different color space or outputting it to a given medium using a certain output device generally alters its gamut. Some of the colors in the original are lost in the process and thus it affects the color gamut.

Color gamut is a key component of expressing how colorfully devices and systems present images to the human color vision system [23]. In other words, the color gamut is the set of colors that can be printed or viewed within a color system, such as a printer, scanner, etc. Figure 5 is a schematic representation of a monitor and a printer gamut.

The theory of color systems states that the gamut of a device or process is that portion of the color space that can be represented in a color space or reproduced in a color system. Certain colors cannot be reproduced in a particular workflow and such colors are said to be out of gamut. It is practically impossible to reproduce all existing colors in the spectrum for any given device with either additive or subtractive colors. These systems render a substitute of all visible color and these substitutes replace the original color that cannot be printed or viewed. There are some colors additive color system cannot reproduce and some that subtractive color system cannot reproduce. [24; 25]

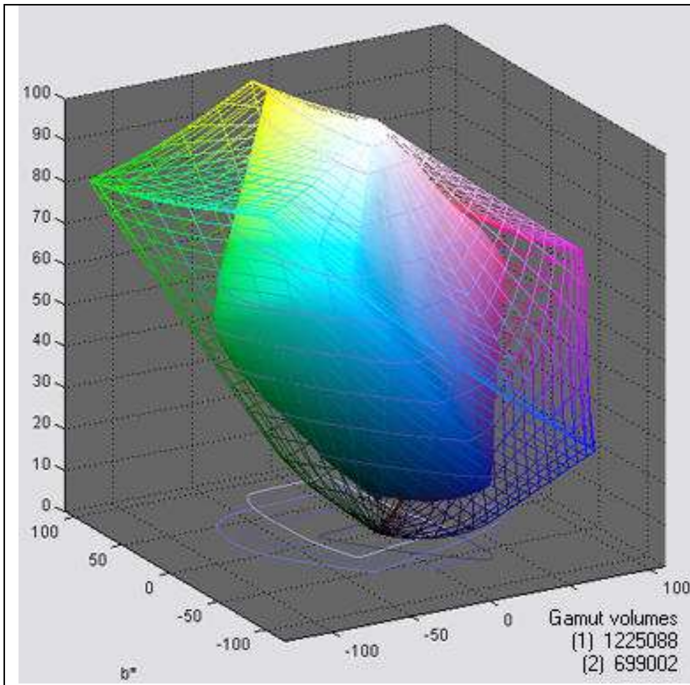

Figure 5: Representation of a color gamut of Monitor and Printer [26]

The RGB model is the most convenient color model for processing a digital image. Printing processes require the image to be converted from the RGB color space to a YMCK color space. The conversion process can lead to loss of some colors that are out of gamut of the particular YMCK color space. Rendering the colors that are out of gamut to the closest colors in the destination space would ruin the image. [27] Thus, it is critical to identify the colors in an image that are out of gamut before converting for the quality of the final product.

Extended Color Gamut

Color is a measurable quantity and the most critical component in determining print quality. It is a fact that, for any output device, the YMCK 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 are involved in which color matching is critical. The basic goal of extended color gamut printing is to expand the pressroom color gamut and to incorporate brand spot colors accurately and cost effectively. [28] Violets, greens and oranges are typically very difficult to match using 4-color process. [29] Extended color gamut printing enables the printer to use a wide range of colors by adding spot color inks to the standard process color inks (YMCK) or by using higher densities of commercially available inks to achieve intense, highly saturated effects that can be seen in Figure 6. The cost saving benefits and added value provided by the precise results makes extended gamut printing a new solution to old problem. [28] It also enables the reproduction of 90 percent of the colors from the Pantone Color System as compared to the process color inks that can reproduce only 60 percent of the colors of the Pantone color system. [30] It also offers a color-critical solution to high impact graphics through the work in prepress and larger value of printable colors. [22]

Figure 6: Difference created by the use of Extended Color Gamut (ECG) as compared to YMCK [31]

This technology is well suited to high-end printing applications; the small dots reproduce the detailed images very accurately and maintain the exact hue and saturation of the printed image. 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. Some of these advantages are demonstrated in Figure 6. Use of a single ink set yields good efficiency on the press, saves time through faster make ready, increases press uptime and reduces downtime. [32] [33]

Along with optimized press conditions, extended color gamut is a result of excellent prepress conditions with respects to proofing technology, color separation and the proper toolset to create reproducible press ready files. [34] [35] 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 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 color difference. Also with the help of standardized ink sets and anilox rollers, color accuracy can be optimized with excellent color density.

General Advantages of Extended Color Gamut are:

- Tremendous improvement in color gamut
- Increase in color saturation and brightness
- Less fluctuation in hues of mixed colors
- Less ink inventory, wash up and return waste
- Enhanced quality and color accuracy
- Precise registration of colors
- Less ink and solvent wastage

- Less hazardous waste

Print Media

Print media properties are essential factors from the point of view of ink and paper interaction and for achieving desirable color matching quality and reproducibility. Combinations of ink and media have a significant impact on color gamut and color stability of the printed files and predetermine color gamut and color stability of the final printed products [(36).] The physical properties, such as roughness and porosity, affect ink penetration, ink spreading, absorption, the final color matching quality and detail rendering quality.

The ink receptivity determines the ink interaction with the paper. The coating layer on the surface can help to attain better control on absorbency of ink. Absorbency of ink is determined by the smoothness or roughness of the surface of the substrate, pore size or porosity and structure as well as its surface energy. Low porosity and low surface roughness results in lower absorbency of the ink and higher ink holdout, thus the outcome is glossy print along with high print density. Alternatively, high roughness yields more ink absorbency that results in more penetration of ink vehicle into the pores, giving a dull and matte finish to the print. Coating layer significantly affects properties, such as gloss, optical density, dot shape, image brightness, color, drying time of ink and it’s compatibility with surface of the substrate [(37)]. It substantially affects the light-fastness of the print, specifically in the case when fluorescent agents are present in the coatings [38]. Optical brightening agents (OBA) are additives used in paper coatings to enhance the brightness appearance of coated and uncoated papers. These OBA absorb from the UV portion of the light and reflect the light in the blue portion of the visible spectrum increasing the brightness of paper. So, these optical brightening agents play a critical role in color reproduction and hence must be taken into consideration. For assessing the possible effects of fluorescent component there are instruments containing an optional UV-absorbing filter that deals with the fluorescent contribution of the substrate.

Selection of the paper with suitable properties is important in order to achieve better quality prints. This selected paper should reproduce fine details by reproducing a good range of tone scales. By using enhanced quality media, high optical density, better stability of color, an exceptional color gamut can be achieved [39].

Role of Color Management

Following are the requirement of color management:

- Consistency of reproduced color: All the colors reproduced from the same image data must look the same across the whole production workflow in image quality as well as in color reproduction.
- Color gamut: The color gamut obtained from the profiles should be consistent across different device measurements.
- Color fastness: The generated output must not change or fade its color within a reasonable time frame [40].

Color management is defined as the system that provides an environment to control and reproduce the colors on various devices consistently and accurately, within the limitations of the device itself. The prerequisites of color management in print imaging are four C's of color management: consistency, calibration, characterization, and conversion (adjustment) of all the devices (41). This aids in reproduction of color images more precisely and has a close resemblance to the original. Cost-effectiveness, easy handling and reliability are other basic requirements for any color management system. The cost of color management in the pre-press stage can be affordable as compared to the cost of stopping the job that is already on press. Color management is very useful for the open loop systems comprising of multiple devices and color reproduction workflows to obtain the accuracy of the color appearance (42). Each device needs to be calibrated and the colors need to be converted to the respective destination color space by means of ICC profiles. The ICC profile structures are defined and standardized by the International Color Consortium (ICC) committee (43).

The ability of the device to obtain good color matching results depends entirely on the effective use of color gamut mapping and the use of profiles for the conversion work. Best results of color matching are obtained by color management. It takes into account the inks, paper, and the devices, viz. scanners, monitors, printers, etc. Press characterization involves fingerprinting followed by ICC profiling, which is essential for producing correct color for the job (44).

Flexographic Printing Process

Flexography is a relief printing process, which is very similar to the letterpress printing process. The image area is raised on the image carrier to carry out printing. In letterpress, the image is made by a metal surface on a flatbed or a hard polymer mounted on a cylinder, whereas in flexography it is made of a soft polymer plate or flexible photopolymer plate. The image areas are formed on the flexible photopolymer by exposing it to light. After exposure, the flexible photopolymer plate is processed by the use of solvents. The solvents wash out the unhardened material leaving a raised image area as the non-image area is mostly comprised of unhardened monomer or prepolymer. Ultraviolet light plays an important role in hardening of the exposed prepolymer plate. A brush system scrubs the plate to aggravate the washing system, increasing the rate of plate production. Computer guided laser system can also be used to make the plates. However, this process is costly and laser equipment is required. [45] [46]

A special tape is used to mount the photopolymer plate on to the plate cylinder. The tape has adhesive on both sides and thus it is termed as ‘sticky back’. Microdots or cross marks are used to mark the correct positioning of the plate on the plate cylinder. One of the most important rollers in the flexographic process is the anilox roller. The anilox roller is a hard cylinder made of steel, ceramic or aluminum. It is coated with ceramic to provide durability. The anilox roller has millions of fine depressions that carry ink from the ink fountain to the plate cylinder. The flexographic press can have the anilox roller partially submerged in the ink fountain or a metering roller that is submerged in the fountain and transfers ink to the anilox roller. The doctor blade scrapes off the excess ink from the anilox roller and the anilox transfers the ink to the plate cylinder. The ink is finally transferred to the substrate with the help of the impression cylinder. The impression cylinder creates enough pressure between the plate and the substrate to transfer the ink from the plate to the substrate. This pressure between the plate and the anilox is termed as 'kiss impression pressure'. If the pressure is, more than that is required, then dot bridging can occur. Figure 7 demonstrates the working principle of the flexographic printing process. Flexible plates, low ink viscosities, solvent based, UV-curable or water based inks, make flexography suitable for a wide variety of substrates from plastic films to packaging boards and thus makes it the most suitable method of printing for packaging. The substrate for water-based inks must be porous enough to absorb the ink, or for nonporous substrates, its surface energy must be high enough to provide print quality and proper adhesion. This will dry the ink film at a fast rate still holding the ink on the surface maximizing color density and ink mileage. [47] [48] [49]

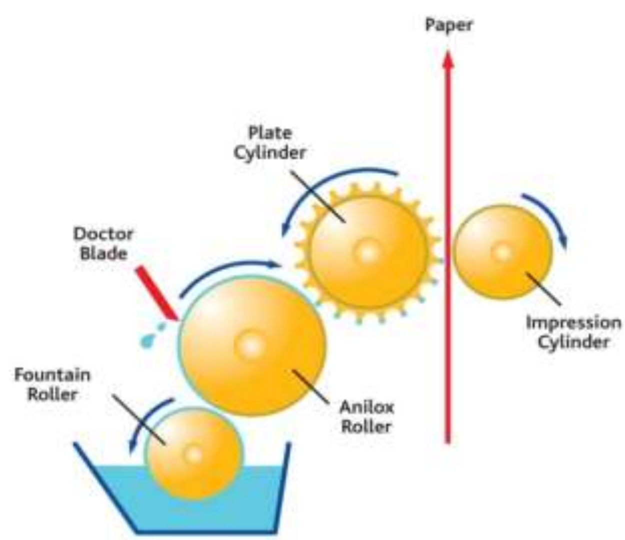

Figure 7: Flexographic Printing Process [50]

Flexographic Inks

Flexography ink is a key component for printing and creating packaging materials. These inks are continually adapted to suit packaging materials as they change so as to maintain printability. Color is the fundamental aspect and determines the quality and superiority of the printed products. [51]

Flexographic inks may be solvent based, water based or UV or EB curable; they are fast drying and have a low viscosity. The inks are formulated so as to be suitable for nonabsorbent substrates and solidify when solvents are removed, mainly by the process of drying by evaporation. Solvents are removed with heat except for UV curable inks or electron beam inks, which dry by a polymerization process. Flexographic inks consist of colorant and vehicle. Colorants are mainly pigments, but also can be soluble dyes. Colorants are mixed with a binder and various solvents to formulate the ink. Solvent based, as well as water based inks may contain various types of alcohols, esters or ethers; water based must not contain more than 5 to 10% of solvents. Alcohol is used as it rapidly dries through evaporation, but it also contributes to VOC (volatile organic compounds) emissions. Other solvents that can be constituted are glycol ether or other ethers. Water based flexographic inks dry principally through evaporation and absorption on paper and similar porous substrates. The evaporation process requires a longer drying time and larger fuel or energy consumption to dry the ink. [51] Coating of papers helps to control the absorption of the ink and thus control over the drying process can be achieved. The high speeds of the presses increase the requirement of the inks, thus increasing the VOC emissions. A pollution control system is necessary to reduce the VOC or control the amount of VOC emitted by the use of solvent-based inks. The need for pollution control system can be eliminated by the use of water based inks and energy curable inks. [3]

Ultraviolet flexographic inks can be used solely or as top coats and lacquers. UV flexographic inks can be used to improve the image quality of flexographic printing. The use of UV curable colored inks in the printing industry is increasing, but is limited by the equipment investment and product concerns are ever more growing that create hurdles that lower the use these inks. Water based and UV curable inks cannot be used with specific substrates due to low surface energy or because of the print design being used. Such substrates and designs provide no other alternative to the printer other than using solvent-based inks. (52) (53) (54)

Significance of Flexography

Packaging, package printing, as well as commercial printing, has wide applications for spot colors, where the desire for colorful appearance of design can be fulfilled. Spot colors are primarily used for printing of logos, or specialty colors. Another important application of spot color is for brand recognition in packaging applications. Flexography can be used for variety of substrates like corrugated, flexible packages, labels, folding cartons etc. Flexography has the prime application in packaging as compared to other markets. (55)

The significance of flexographic printing can be stated due to following factors:

Versatility: Flexography can print on a variety of substrates and makes use of fast-drying inks, which makes it ideal for packaging printing. It has applications in the production of newspapers, labels, disposable materials, etc. It can print on porous as well as nonporous materials, such as paper, metallic films and foil, cardboard, etc. Wide varieties of inks are available, including water-based, UV-curable, solvent based colored or specialty fluorescent and metallic inks.

Speed of production: Flexography has a short press setup or make-ready time. Flexography presses use low-viscosity and fast-drying inks, making the printing process still faster. Use of water-based or UV curable ink in flexography considerably shortens the cleanup process and consumes less time. Other processes, such as laminating and die cutting can be easily modified and assimilated with the press line, making the production a continuous and fast process.

Lower costs: Flexography boosts high-speed and high-volume production, making it a cheap and effective solution over other printing processes. Faster make-readies, press runs and cleanups increase the production, increasing the profit margin considerably. It also provides lower operating costs, thus providing high quality printed products at cheaper rates. Cheap parts and low maintenance costs are other advantages, as a flexible photopolymer relief plate can last long and can turn out millions of impressions. In addition, frequent replacement of the plates is not necessary.

Reduced environmental impact: Flexographic printing uses solvent-free inks on a variety of substrates, thus reducing the emission of volatile organic chemicals (VOC). Presses are equipped with mechanisms for recycling spent ink, wash waters, and thus help reduce the amount of harmful chemicals released to the environment. [4] [47] [49]

Chapter III

Problem Statement

Flexography is competing with lithography and gravure to produce better quality products. Flexographic inks use a variety of pigments, such as organic, inorganic; process color and some other colors known as spot colors. Spot colors fall out of the color gamut formed by the process colors and are typically used for brand building, logos and product branding. The need for extended color gamut is due to the advancement in technology that creates a drive for better and better print quality. The extended color gamut ink sets can provide vivid imagery with the use of fewer printing stations. The use of these ink-sets lower the inventory of the inks as it eliminates the need to have a large number of spot colors in the storage. However, there is a lack of information about these ink-sets concerning color sequence and the types of inks and ink-sets that will yield optimal results during the printing process. The transparency and color properties of the inks can be used to estimate the proper ink sequence that can yield larger enhancements of the color gamut for that specific ink set. Different ink systems can enable advantages like more coverage of area and good control over the ink hues.

This thesis was targeted towards the investigation of extended color gamut reproduction for the flexographic printing process by the use of single pigmented (mono pigmented) inks and two pigmented inks. In addition, the aim was to study the change in the color gamut due to the change in the printing order of the ink sets. A variety of ink sequences was implemented and the color gamut, transparency and trapping of the inks were studied. The results were produced by calculating chromaticity and opacity between the different print sequences from a flexographic attachment on a K-proofer and calculating the color gamuts by profile inspector of CHROMiX ColorThink Pro 3.0. Along with the calculation of opacity from reflectance and from transparency, a correlation equation was generated by using general regression, which can be used to predict opacity values from direct measurement or vice versa. Two printing trials were conducted on AL20L3 Mark Andy eight station flexographic press, in which print trial 1 focused on studying the color gamut on different substrates with two ink sets – mono pigmented and dual pigmented. Print trial 2 was conducted in order to study the color gamut on a single substrate – semi gloss litho with a change in different print sequence for both mono and dual pigmented ink sets. Overall, this project helps to understand and clarify the abilities of extended color gamut to reproduce a variety of spot colors for the flexographic printing method.

Chapter IV

Materials and Methods

As this research work was concentrated on printing of extended gamut, therefore different software, substrates for printing and color measuring instruments were used. Table 1 describes in detail all the equipment, material and software used for this research work.

Table 1: Equipment, software and materials used for thesis project

	Equipment, Materials and Software
Inks for Printing	Print trial: Water based flexographic inks – Cyan, Magenta, Yellow, Black, Orange, Green and Violet, Orange 2-pigmented, Green 2-pigmented, Violet 2-pigmented. (SunChemical)
Flexo printing Substrate	Semi-gloss Litho label stock, PET (Poly Ethylene Film)
Profiling Software	GretagMacbeth ProfileMaker Pro 5.0.8.
ICC Profiling Test Chart	ECG-WMU-7C Test Chart
Measuring Tools	i1-iO Spectrophotometer (X-Rite)
Inspecting Tools	CHROMiX ColorThink Pro 3.0

Experimental Design and Procedures

The research work was divided into several different tasks, which are:

- 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 GretagMacbeth 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. Table 2 shows the physical properties of the substrate.

Table 2: Physical Properties of the semi-gloss litho label substrate

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^{o} [%]	60.5
Caliper [µm]	145

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 by Technidyne Brightimeter Micro S-5. The Semi-gloss Litho substrate was backed with release liner.

Print Trial

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.

Table 3: Press Trial

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)

Inks for Print Trial

Water based flexographic inks were used for the print trial. All the water based flexographic inks used for the print trail were donated and premixed by Sun Chemical, and they were further matched by printing on the flexographic press. The viscosities of provided inks were adjusted and maintained at 22 sec to 25 sec. (#2 Zahn cup), by addition of ammonia water before starting the print trial. Viscosity of inks was adjusted to match solid color CIELAB color targets. During the entire print trial the viscosity of ink was checked and maintained at 22—25 sec. efflux time for the rest of the trial.

CIELAB Measurement

CIELAB values and the reflectance spectra were measured with the help of an X-Rite i1iO spectrophotometer with 45^o / 0^o geometry. Profile Maker 5.0.8 was used to make the ICC profiles for each ink set and substrate combinations. Gamut volumes were created by using ColorThink 3.0 Pro and with the help of ProfileEditor 5.0.8.

Test Chart

Figure 8: Test Chart with 7 channels, YMCK + OGV

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 chart, as shown in Figure 8, shows the target with a total of 1560 patches. It 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.

Opacity Calculation

Opacity is the optical property or the hiding power of the ink dealing with the interaction of ink layer and light passing through its printed film. A laboratory K-proofer (Figure 9), in flexo mode, was used to take prints and measure opacity of dried printed ink film. The prints were taken on Leneta a chart, which has white and black areas, and opacity was calculated by measuring the XYZ values taken over white and black backing. The percent opacity can be calculated by using the standard test method ASTM D 2805-11. [56]

Figure 9: K-Proofer.

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. Opacity is generally represented in percentage. Figure 10 shows the drawdown of orange spot color ink on Leneta test sheet, on black and white patches.

Figure 10: Printed ink on white and black areas on Leneta sheet.

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%.

In order to calculate the opacity of the ink, the reflectance data of each ink from black and white patch were measured by an i1-iO spectrophotometer (X-

Rite). Respective tristimulus values were used to calculate the opacity for the individual as well as overprinted inks according to Equation (1). For example, only X values of reflectance were used for orange spot color ink, only Y values were used for green ink and only Z values for violet ink. Figure 16 shows the final calculated opacity values for each color.

$$\text{Opacity of Ink (\%)} = \frac{Rb}{Rw} \times 100 \qquad \text{(Equation 1)}$$

Where

Rb is respective reflectance value from black area

Rw is respective reflectance value from white area

The ink sequences that were compared were as follows:

- YM vs. MY
- YC vs. CY
- OM vs. MO
- OK vs. KO
- OC vs. CO
- GC vs. CG
- GK vs. KG
- MC vs. CM
- VK vs. KV

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 [57] [58]. In other words, chroma is an objective specification of the quality of a color regardless of its luminance. In this work, it was very important to identify what role the chroma plays in color gamut of differently printed sequences.

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 and i1/iO spectrophotometer and compared.

The formula used to calculate chroma can be stated as follows:

$$C^*_{ab} = \sqrt{a*^2 + b*^2} \quad \text{(Equation 2)}$$ [59]

Where

$C_{ab}*$is the Chroma

a* and b* are the redness/greenness and yellowness/blueness values of CIELAB system

Particle Size

Particle size can be defined as three dimensional object having attributes length, breadth and width. It is difficult to predict particle size by taking only one attribute in to consideration. The particle size analyzer considers the shape of the particle to be spherical and thus the measured attribute is the diameter of the particle. It simplifies the representation of particle size. The particle size was measured using a NICOMP 370 from Particle Sizing Systems. The refractive index was set to 1.333 and the specific density of water was set to 0.933, which is a standard for water based inks. The intensity set between 250 to 300 KHz to improve efficiency of measurement for samples that scatters light adequately. Average length of measurement is about 30 min in order to provide optimum results.

Correlation Equation

A correlation equation describes a relationship or association between two variables. The relationship can be linear, quadratic or algebraic. A simple representation of correlation equation can be stated as Y = a + b*X; where 'a' & 'b' are the coefficients that and 'X' & 'Y' are the variables. One of the most important aspects of correlation is the strength. The strength of the linear association between two variables can be quantified by the correlation coefficient 'r'. The correlation coefficient directly relates to the regression line (Y = a + b*X) for any two variables because the regression line involving the least square values of ‘r’ passes through the means of X and Y. The regression line can also represented completely by the means, standard deviations, and correlation of the two variables. [60] In linear regressions ‘r^2’ is used more often and is termed as the coefficient of determination. [61] The main purpose of ‘r^2’ is to take in to account the proportion of variability and to predict future outcomes on the basis of the related information. The value of the coefficient of determination ranges between -1 and 1; a value of zero for *r* does not signify that there is no correlation; a correlation in such cases could be a nonlinear. However, even a nonlinear correlation will usually yield a non-zero correlation coefficient. The formula to calculate r is as follows:

$$r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)^2}} \quad \text{(Equation 3)}$$

[62]

In this work, two inks were overprinted by using the K-proofer on a PET substrate, as well as on Leneta sheets. A tone step patterned flexographic plate was used with tone steps of 25%, 50%, 75% and 100. The aim of this research work was to quantify the relationship between two methods of calculation of opacity, i.e. opacity calculated from SpectroScan T and opacity calculated by i1/iO Spectrophotometer.

Chapter V

Results and Discussion

This research work concentrated on the extended color gamut for the flexographic prints. Different ink sequences were incorporated in the flexographic press trail with different run orders. Gamut volumes, as well as opacity and transparency of color overprints, were studied after the print trials. The results are discussed based on the print trials and subsequent experiments.

Particle Size

Inks and their components serve many purposes during printing process. The vehicle, colorants, and other additives control the flow and viscosity of the ink and also affect its appearance after it passes through the dryer. Exposed surface area determines the color strength of the pigment where a smaller particle size produces a stronger color and vice versa. Other properties of ink are also affected by the pigment particle size such as saturation, opacity or transparency, and viscosity. [(63) (64)]

The most important correlation between opacity of the ink and particle size is that the opacity of the ink tends to maximize at a mean particle size of around 400 nm, middle of the wavelength of visible spectrum. [(65)] Figure 11 shows the mean diameter of pigment particle size of all of the inks i.e. cyan, magenta, yellow, black, orange, green and violet. Violet2, orange2 and green2 represent two pigmented inks whereas all other inks are single pigmented ink sets. Figure

11 represents the particle size diameter using intensity as well as volume distribution of particle size.

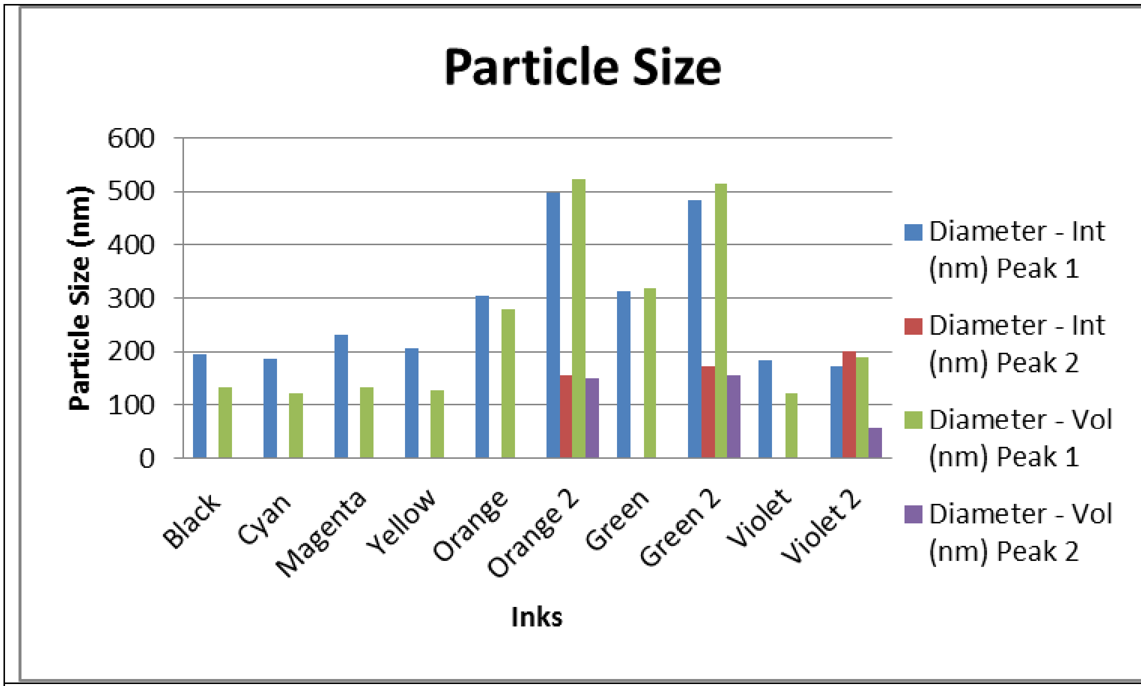

Figure 11: Particle size of single and two pigmented inks

The mean diameter for the intensity distribution had an average value between 200 to 300 nm and for volume distribution was found between 100 to 320 nm. There were larger standard deviations for volume intensity and lesser standard deviations for intensity distribution. Two peaks are observed for dual pigmented inks with peak 2 being of considerably lower than peak 1.

Particle size also plays an important role in ink rheology. A reduction in particle size increases the suspension viscosity. [(63)] Particle size distribution is another important physical property requiring measurement and control. In general, a wide particle size distribution reduces color strength (chroma) and can be indicative of poor color stability. (66)

Gamut Volume

The color gamut is the range of colors that can be printed using a particular media, ink, or process. (23 67) Mathematically, the color gamut volume, a volume in CIELAB space, is the number of colors that are discernable within a ΔE tolerance of $\sqrt{3}$. (23) The monitor has larger color gamut than the YMCK printed job and thus rendering intents are used to deal with out-of-gamut colors. (68) Printed patches were measured in CIELAB color space and profiles were created that converted colors specified in a device dependent color space to device independent color space. By measuring these charts and creating their profiles, it was possible to determine the gamut volume of the printed samples.

Comparison of the gamut volume of YMCK profile and YMCKOGV profiles are shown in Figure 12. The gamut volumes were calculated from the ICC profiles that were created using Profile Maker 5.0. Profile inspector CHROMiX ColorThink 3.0 Pro was used to calculate the gamut volumes of the profiles, which were then plotted (Fig.12).

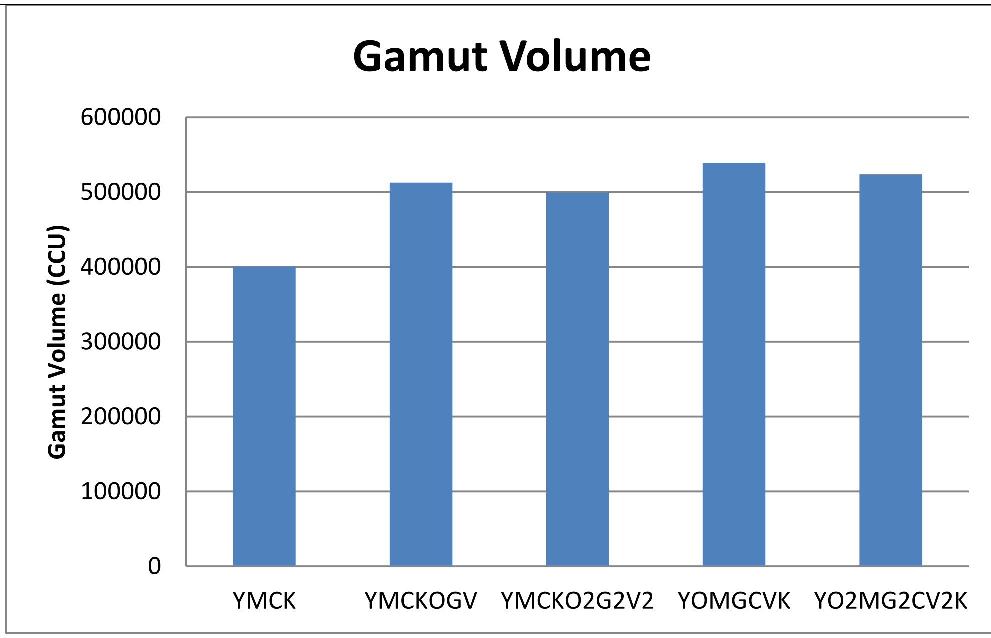

Figure 12: Gamut volume of YMCK and YMCKOGV with single and dual pigmented inks

The color gamut of YMCK print on Semi-Gloss Litho substrate was 401,000. 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. 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 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 transparency of the respective inks.

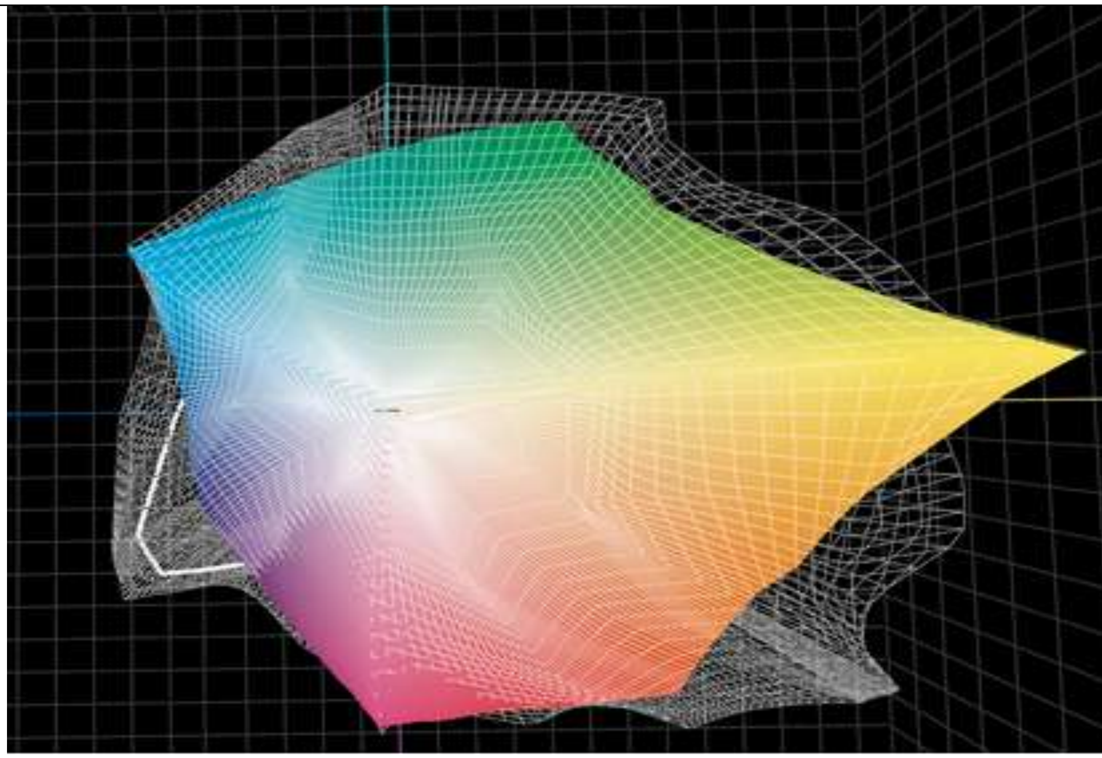

Figure 13: Comparison of YMCK color gamut (Colored) to YOMCGVK gamut (Wire Frame) of single pigmented inks

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 Figure 11 illustrates the gamut of YMCK and the gamut of YOMGCVK for single color. 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.

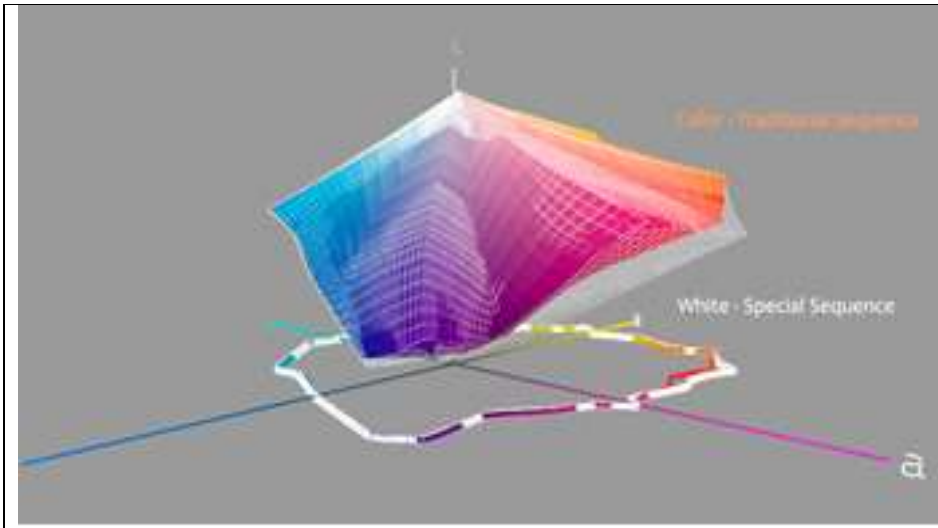

Figure 14: Comparison of gamuts of YOMCGVK (Wireframe) and YMCKOGV sequence (Color) of single pigmented inks

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, which is demonstrated in the Figure 12

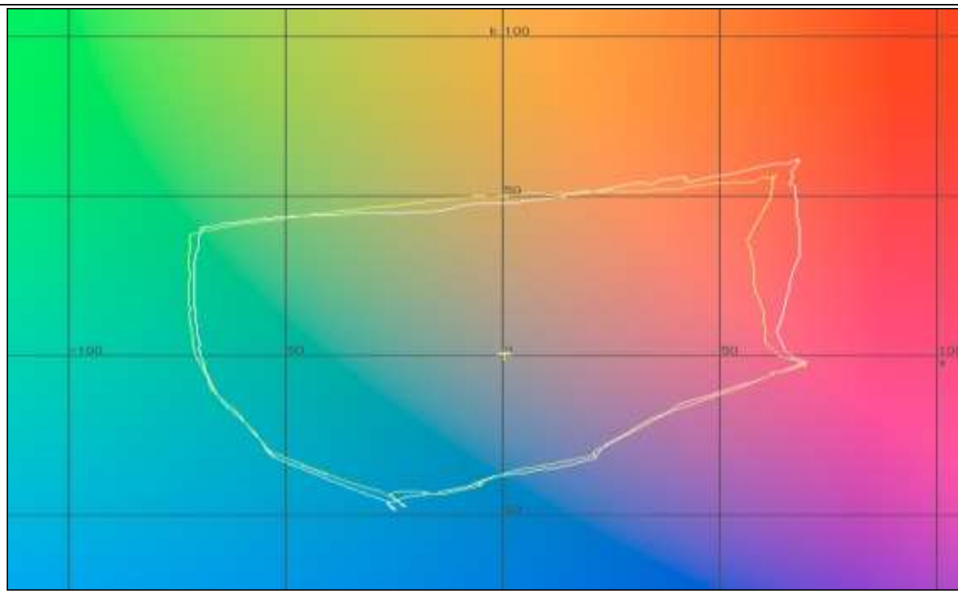

Figure 15: 2-D Projection of YOMCGVK (white) and YMCKOGV sequence (yellow) for single color inks

Comparing YMCKOGV print order to YOMGCVK, it is observed that the apparent increase of gamut is seen in mainly in the magenta-red- orange –yellow area for single pigmented ink system (Fig. 15). Changing the order from YMCKO2G2V2 to YO2MG2CV2K for two pigmented ink system produces a gamut increase in yellow- orange-red and yellow- green area, which can be seen in Figure 15. 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, in next chapters the attention is oriented towards examining of overprints of the colors and their properties.

Opacity Calculation

In order to better understand the behavior of inks and their overprints, draw-downs of single inks and their combinations in different order was made. Order is given in Experimental. Opacity was calculated from respective XYZ values according to Equation (1), and the values are illustrated in the Figure 16.

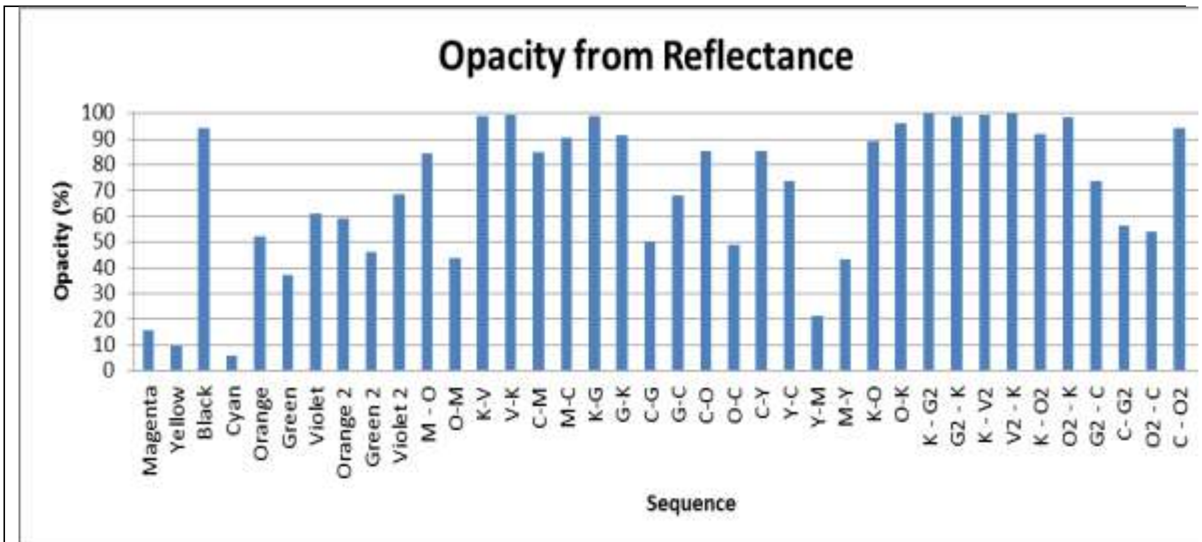

Figure 16: Opacity of single inks and overprints of two inks.

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 O. 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 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 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

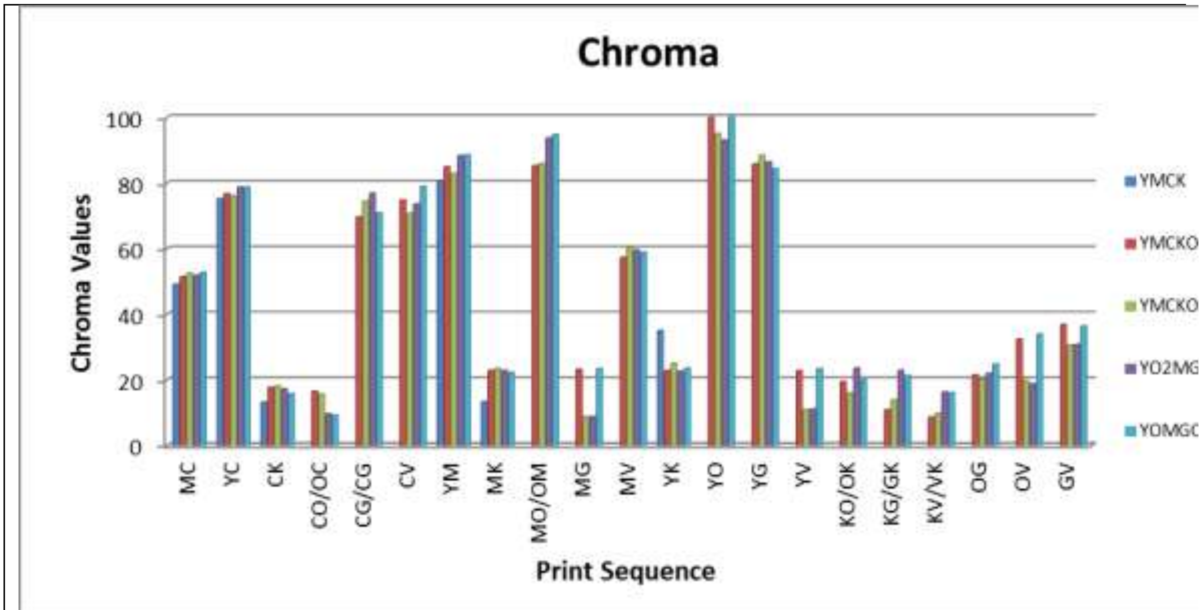

Figure 17: Chroma values calculated from printed sheets

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 (Figure 17). 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 over print 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 best results for ECG printing.

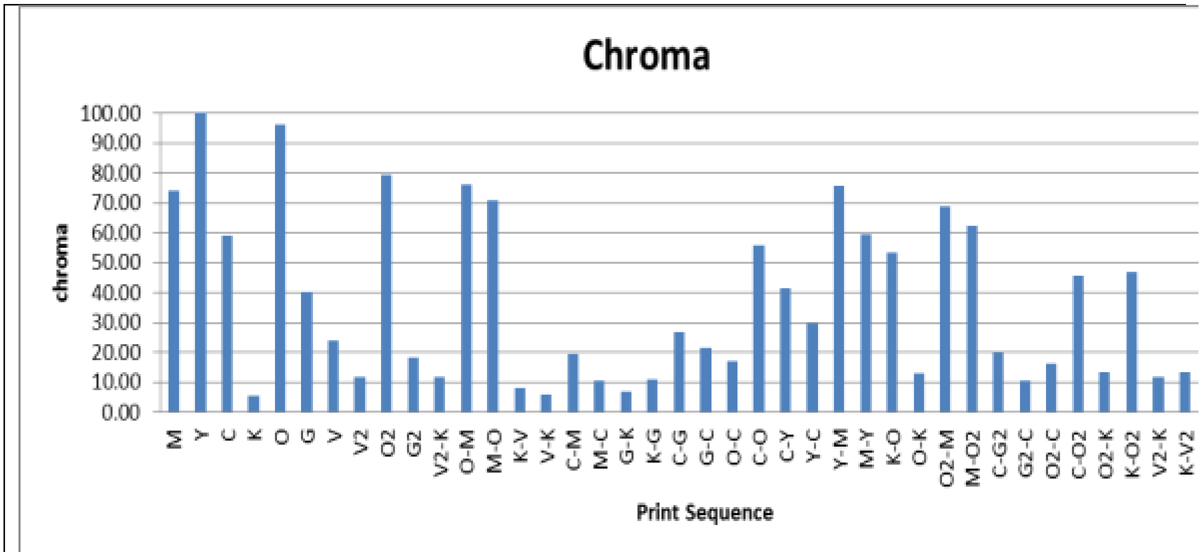

Figure18: Chroma values calculated from K-proofer prints

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 has relatively lower chroma values as compared to that of single pigmented inks. The print order that produced 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.

Reflection and Transmission

Spectral reflectance curve can be defined as a curve that demonstrates the reflectance of light from a surface of a substrate. The reflectance curve is plotted wavelength-by-wavelength throughout the visible spectrum and servers as a means of determining the color of that surface. Spectral reflectance also aids in determining paper color, brightness, and whiteness and also vital optical properties that vividly affect the quality of material printed on the paper surface like color gamut in this case.

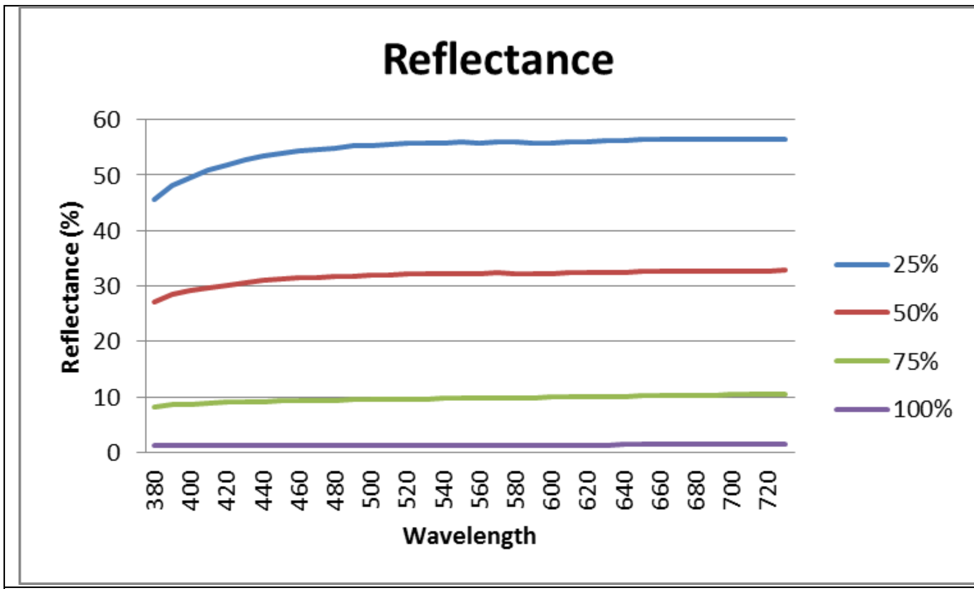

Figure: 19 Reflectance curve of black ink

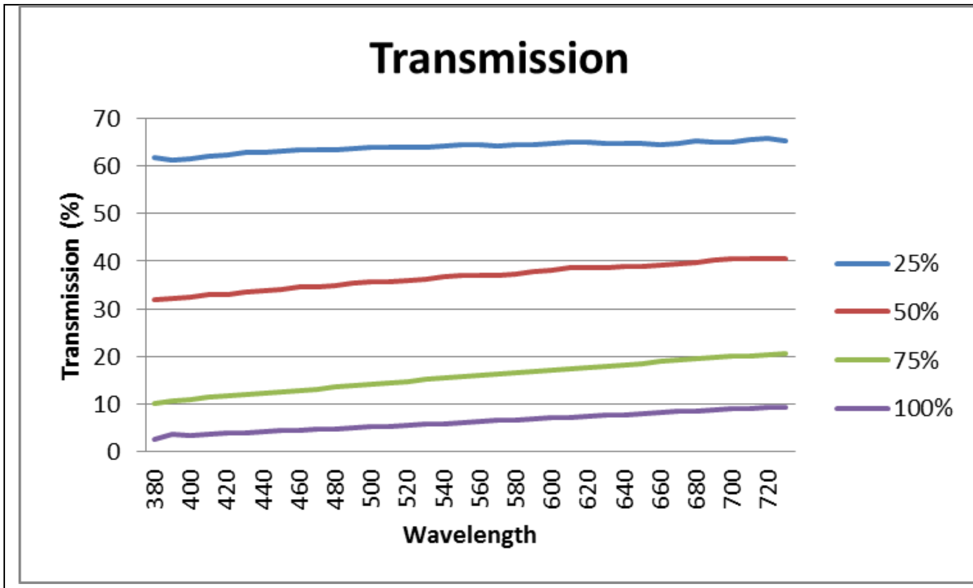

Figure 20: Transmission curve of black ink

The Figures 18 and 19 show head to head comparison of spectral reflectance and transmission curves of black ink and these were recorded by the use of X-Rite I1/IO spectrophotometer and SpectroScan T, respectively. The reflectance was measured from the prints obtained from the K-Proofer printed on the Leneta sheets. The transmission on the other hand was obtained from the prints of K-Proofer printed on PET substrate.

It can be clearly seen from the graphs that transmission curves have values that are slightly higher or equal to the reflectance curves. The SpectroScan T plots the values that are obtained by transmission of light through the substrate whereas for reflectance curve the light is reflected back from the surface of the paper. In the reflection process some of the light is diffused in the substrate, which causes the recorded value to be slightly lower. Some reflection is also observed in transmission curve but the diffusion of light in the substrate is much lower and thus the recorded values are slightly higher. Also in reflection the light involves two passes through the ink film whereas in transmission the light only passes once through the ink film.

Correlation Equation

The opacities were measured for all the patches by both methods and a general regression was performed to get the correlation equation. Only single pigmented inks were used for this study as they gave better printing results. The Figure 21 shows the opacities calculated from reflectance data, using XYZ values measured over white and black background according to equation 1.

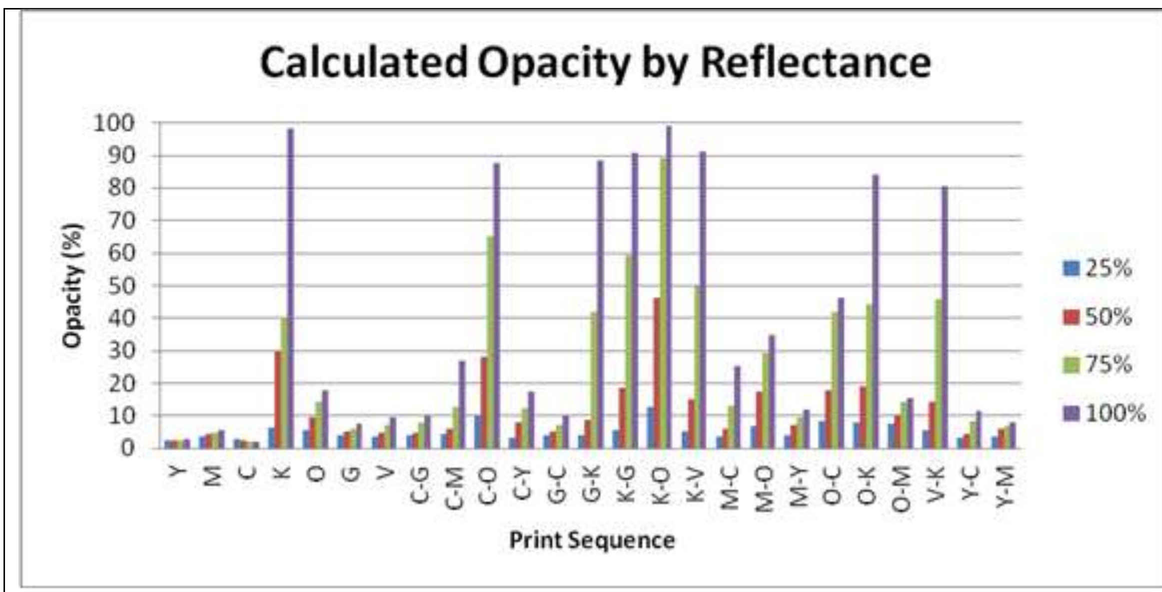

Figure 21: Opacity calculated from reflectance by I1/IO Spectrophotometer

The transparency was calculated by measuring the XYZ values from SpectroScan T and normalizing to the film. The XYZ values of the film and ink on the film are recorded. The values for the ink on film are divided by the corresponding XYZ values of the film and thus the transparency is normalized. The opacity from transparency was calculated by subtracting the transparency from 100. Thus the opacity is obtained in percentage.

The equation for calculating the transparency can be stated as:

$$\text{Transparency of Ink (\%)} = (T_i/T_f) \times 100 \qquad \text{(Equation 4)}$$

Where:

T_i is the Transmission from given area of ink

T_f is the Transmission from the given area of film

Both the opacities were compared and treated as variables for the general regression. The opacity by transmission was termed as response and opacity by reflectance was termed as factor. Figure 22 shows the calculated value of opacities from transmission.

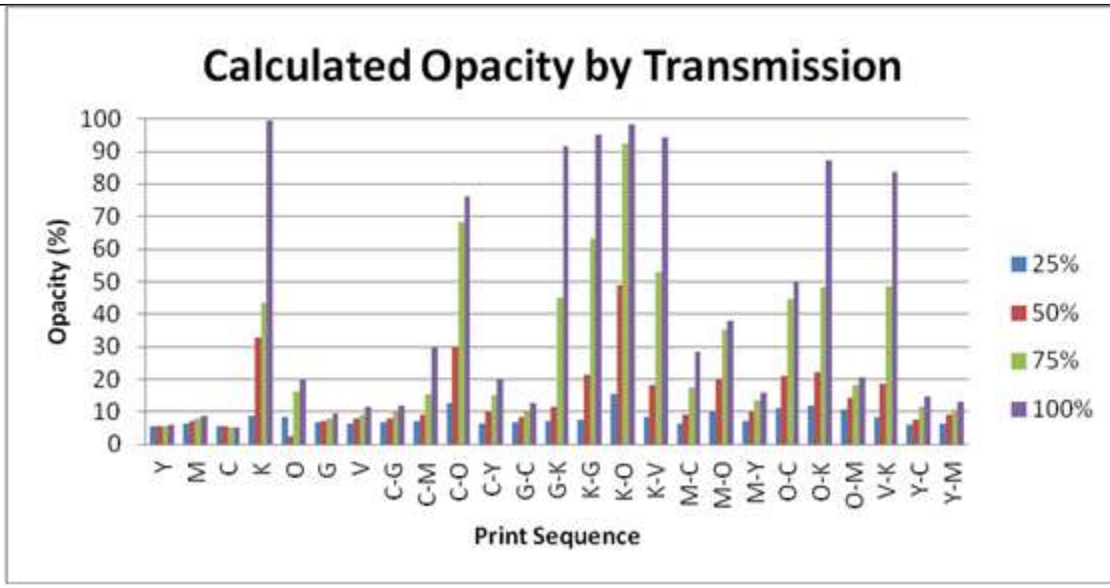

Figure 22: Calculated opacity from transmission by SpectroScan T

The transparency is obtained by measuring the transmission of light through a substrate with the SpectroScan T and i1/iO Spectrophotometer obtains opacity by measuring the reflectance of light from the ink surfaces on the Leneta sheet. The opacity is then calculated by subtracting the transparency from 100.

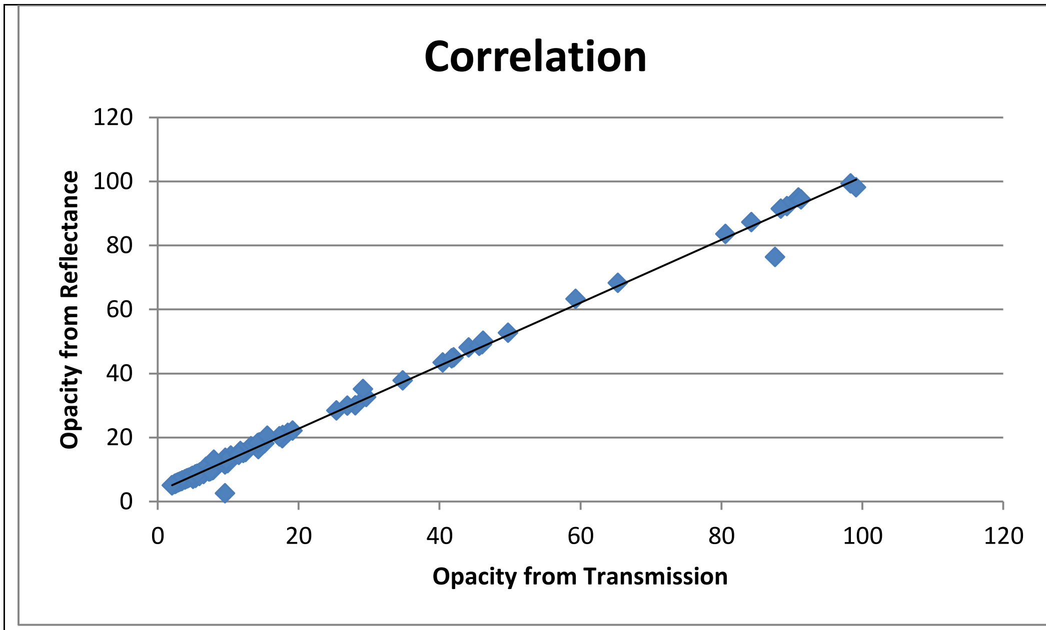

Figure 23: Graph of Correlation between O_T and O_R

The correlation equation describes a linear relationship between the opacity calculated from transmission and opacity recorded from reflectance. As seen in figure 23 the correlation between opacities calculated from the two different methods has a very linear relationship. Thus, if one of the opacities is available then the other opacity can be calculated by using Equation 5.

$$\text{Opacity (from transparency)} = 3.1 + 0.98 \text{ Opacity (reflectance)}$$

(Equation 5)

The calculation of 'r^2' determines the strength of the linear association (regression). The value of 'r^2' ranges from 0 to 1. The value closer to 1 suggests strong linear relationship and closer to 0 suggests the relationship might not be linear or there might be no relationship at all. The Table 4 shows the 'r^2' values for 25% to 100% dot patches. From the calculated values it is safe to say that the relationship between opacity calculated from transparency (a direct measurement) and the opacity calculated from reflectance has a strong linear relationship and can be used for prediction of opacities if one of the values is known.

Table 4: Calculated values 'r^2'

Dot Percentage	'r^2' values
25%	0.880
50%	0.863
75%	0.898
100%	0.893

Chapter VI

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 for a flexographic press. The prints were obtained by printing with the help of an eight-station AL20L3 Mark Andy 2200 flexographic press. Different key factors, which play a crucial role in producing a color gamut, were investigated, such as influence of substrate, influence of ink pigments, print order of individual inks and their effect on gamut volume. In this project, it was desirable 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.

The particle size affects the opacity of ink in many ways. The higher particle size gives higher opacity but the color strength is inversely correlated to the particle size, thus the color strength reduces with higher particle size. The opacity measured is highest at the mean diameter of the particle size and thus it is very crucial to maintain the particle size of the pigments. In the mono pigmented ink there is only one pigment that affects the light interaction whereas the dual pigmented inks have two pigments and thus there are two peaks observed in the results.

Color gamut is used as a measure of color reproduction capability of a device. Changing the print sequences has a huge 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 different overprints were measured to provide evidence to the result of YOMGCVK producing the highest color gamut. Chroma of different ink overprints were compared by changing print orders. Higher chroma produces more vivid and saturated colors. Combination 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. 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. Green and violet ink had a significant contribution 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.

Another goal of this work was to determine if the opacity, calculated from XYZ values of ink film printed over black and white substrate can be correlated with the ink film transparency. Series of opacities and transparencies were measured and correlated. General regression specifies a linear equation between the calculated opacities i.e. calculated from transmission and reflection. The 'r^2' values that were obtained indicate strong linear relationship between the opacities and transparencies. The equation is an excellent way of comparing the opacities calculated by two different methods. It also makes it possible to predict the value of opacity for one method if one of the values for other method is known. It also provides a relation between ASTM D2805 Opacity and a direct measurement of opacity. This relationship confirms the validity of ASTM D2805 Opacity.

Software used

1. GretagMacbeth Measure Tool
2. GretagMacbeth ProfileMaker 5.0.8
3. Adobe Photoshop CS-4
4. Chromix ColorThink 3.0 Pro

Substrates used

1. Coated Semi-Gloss Litho Paper
2. Poly Ethylene (PET)

Instruments used

1. X-Rite i1/i0
2. X-Rite 530 SpectroDensitometer
3. K-Proofer (R.K. Print)

Tests Performed

1. CIE L*a*b* Values of printed charts, K-proofer prints and overprints, calculation of Opacity
2. XYZ values for calculation of opacity/transparency from single prints and overprints of two ink sets on BYKO chart and PET film
3. Profiles for plotting Color Gamut

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Appendix

Table 5: Opacity of printed ink from reflectance

Color	Opacity (%)
Magenta	15.64
Yellow	9.47
Black	94.39
Cyan	6.05
Orange	52.29
Green	37.28
Violet	61.15
Orange 2	59.38
Green 2	46.32
Violet 2	68.50
M - O	84.46
O-M	43.85
K-V	98.78
V-K	99.52
C-M	84.84
M-C	90.53
K-G	98.80
G-K	91.61
C-G	49.70
G-C	68.08
C-O	85.49
O-C	48.94
C-Y	85.33
Y-C	73.69
Y-M	21.35
M-Y	43.36
K-O	89.23
O-K	96.33
K - G2	99.61
G2 - K	98.82
K - V2	99.48
V2 - K	99.90
K - O2	92.07
O2 - K	98.30
G2 - C	73.57
C- G2	56.49

O2 - C	54.18
C - O2	94.32
M - O2	89.67
O2 - M	47.89

Table 6: Particle size of the single and dual pigmented ink

Color	Time (min)	Mean Diameter - Int (nm)	Std Dev	Mean Diameter - Vol (nm)	Std Dev
Black	25 – 30	194.2	88.2	133.6	60.7
Cyan	25 – 30	186.2	85.7	123.1	56.7
Magenta	25 – 30	232.4	139.3	133.6	80.1
Yellow	25 – 30	207.5	108.8	128.4	67.3
Orange	25 – 30	304.5	164.6	279.7	151.2
Orange 2	25 – 30	286.3	145.9	257.4	131.2
Green	25 – 30	312.8	145.6	318.2	148.1
Green 2	25 – 30	282.4	144.3	249.6	127.6
Violet	25 – 30	185.3	86	121	56.2
Violet 2	25 – 30	172.9	93.1	89.2	48.1

Table 7: Measured color gamut for different ink sequences

Color Sequence	Gamut Volume
YMCK	400511
YMCK + OGV Mono Pigment	512493
YMCK + OGV Dual Pigment	499276
YOMGCVK Mono Pigment	539321
YOMGCVK Dual Pigment	523913

Table 8: Chroma values calculated from K-Proofer prints

Color	Chroma
M	74.05
Y	119.92
C	58.94
K	5.51
O	96.15
G	40.51
V	23.87
O2	79.37
G2	18.35
V2-K	11.97
O-M	76.31
M-O	70.80
K-V	8.10
V-K	6.00
C-M	19.66
M-C	10.56
G-K	6.73
K-G	10.87
C-G	26.99
G-C	21.38
O-C	17.18
C-O	55.77
C-Y	41.60
Y-C	29.63
Y-M	75.72
M-Y	59.63
K-O	53.56
O-K	13.14
O2-M	68.99
M-O2	62.34
C-G2	19.92
G2-C	10.74
O2-C	16.43
C-O2	45.67
O2-K	13.53
K-O2	46.79
V2-K	11.62
K-V2	13.33

K-G2	12.17
G2-K	7.45

Table 9: Chroma Values calculated from pressrun prints

Sequence	YMCK	YMCKOGV	YMCKO2G2V2	YO2MG2CV2K	YOMGCVK
MC	49.095	51.408	52.512	51.761	52.705
YC	75.177	76.694	76.028	78.754	78.696
CK	13.200	17.693	18.069	17.225	15.730
CO/OC	0	16.507	15.639	9.650	9.201
CG/CG	0	69.595	74.451	76.858	70.906
CV	0	74.787	70.750	73.562	78.939
YM	80.723	84.895	82.822	88.338	88.534
MK	13.328	22.863	23.448	22.831	22.174
MO/OM	0	85.218	85.859	93.606	94.674
MG	0	23.212	8.765	8.766	23.393
MV	0	57.269	60.209	59.549	58.845
YK	34.983	22.793	25.028	22.562	23.523
YO	0	101.501	95.038	92.990	102.211
YG	0	85.754	88.441	86.394	84.293
YV	0	22.819	10.868	11.035	23.373
KO/OK	0	19.395	15.939	23.574	19.985
KG/GK	0	10.884	13.866	22.872	21.287
KV/VK	0	8.610	9.735	16.289	16.043
OG	0	21.504	20.219	21.990	24.766
OV	0	32.379	19.766	18.793	33.946
GV	0	36.851	30.563	30.748	36.420

Table 10: Calculated opacity from reflectance

Opacity	25%	50%	75%	100%
Y	2.53	2.55	2.51	2.90
M	3.48	4.29	4.93	5.60
C	2.70	2.40	2.05	2.03
K	6.51	29.60	40.44	98.33
O	5.42	9.54	14.29	17.62
G	3.87	5.01	5.91	7.45
V	3.39	4.94	7.29	9.58
C-G	3.83	4.73	7.86	9.95
C-M	4.25	5.95	12.48	26.90
C-O	9.72	28.05	65.30	87.63
C-Y	3.20	7.73	12.15	17.26
G-C	3.86	5.34	7.00	9.76
G-K	3.95	8.65	42.02	88.42
K-G	5.36	18.47	59.31	90.95
K-O	12.42	46.06	89.29	99.12
K-V	5.27	15.15	49.73	91.30
M-C	3.47	6.03	13.24	25.38
M-O	6.72	17.29	29.13	34.78
M-Y	4.08	7.061	9.60	11.73
O-C	8.23	17.74	41.77	46.17
O=K	7.91	19.16	44.13	84.24
O-M	7.56	10.37	14.19	15.57
V-K	5.42	14.40	45.61	80.55
Y-C	3.01	4.46	8.35	11.49
Y-M	3.52	6.02	6.86	7.99

Table 11: Calculated opacity from transmission

Opacity	25%	50%	75%	100%
Y	5.53	5.55	5.51	5.90
M	6.48	7.29	7.93	8.60
C	5.70	5.40	5.05	5.03
K	8.51	32.62	43.44	99.33
O	8.42	2.54	16.29	19.69
G	6.87	7.01	7.91	9.45
V	6.39	7.94	9.29	11.58
C-G	6.83	7.73	9.86	11.95
C-M	7.25	8.95	15.48	29.90
C-O	12.76	30.05	68.30	76.36
C-Y	6.20	9.73	15.15	20.28
G-C	6.86	8.34	10.00	12.76
G-K	6.95	11.65	45.02	91.42
K-G	7.36	21.47	63.31	94.95
K-O	15.46	49.06	92.29	98.12
K-V	8.29	18.16	52.73	94.30
M-C	6.49	9.03	17.24	28.38
M-O	9.75	20.29	35.13	37.78
M-Y	7.09	10.06	13.60	15.73
O-C	11.27	20.74	44.71	50.17
O=K	11.98	22.16	48.13	87.24
O-M	10.56	14.37	18.19	20.57
V-K	8.42	18.40	48.61	83.55
Y-C	6.01	7.46	11.35	14.49
Y-M	6.52	9.02	10.86	12.99

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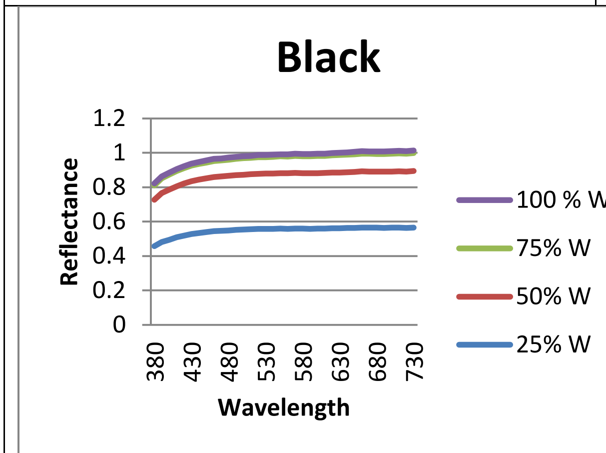
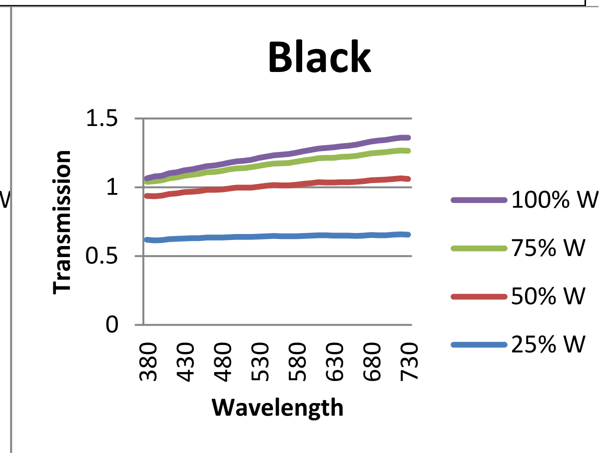
<tr><td>
</td><td>
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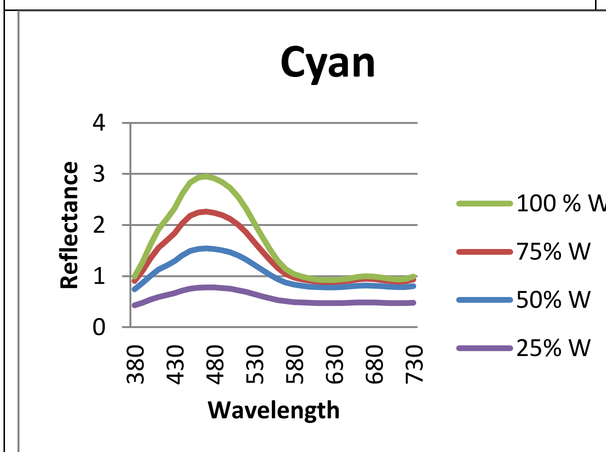
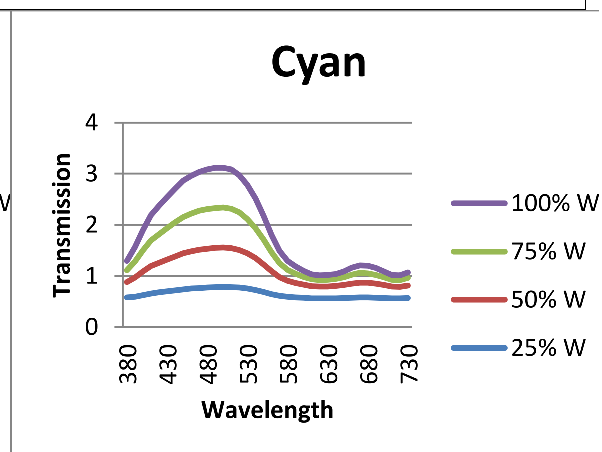
<tr><td>
</td><td>
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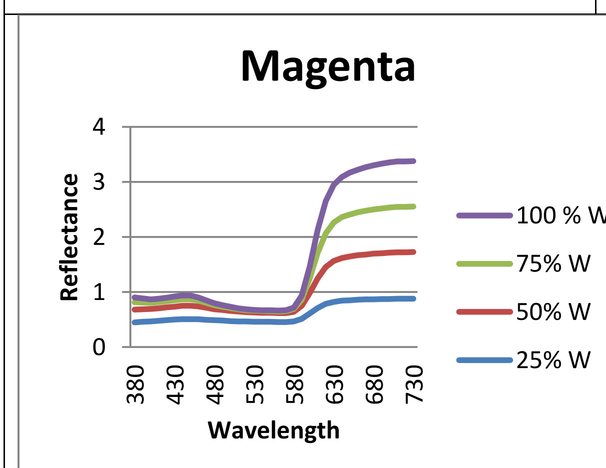
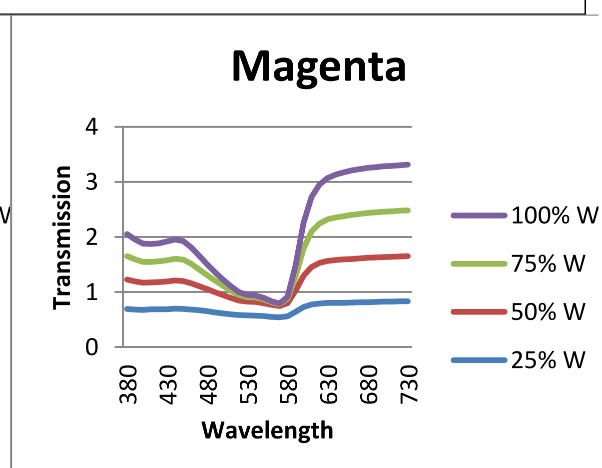
<tr><td>
</td><td>
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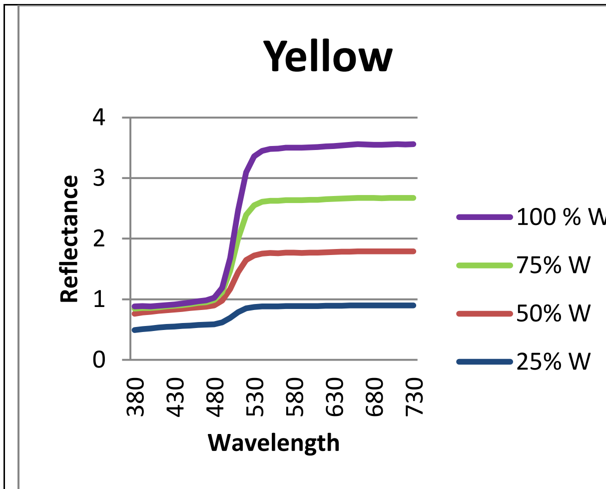

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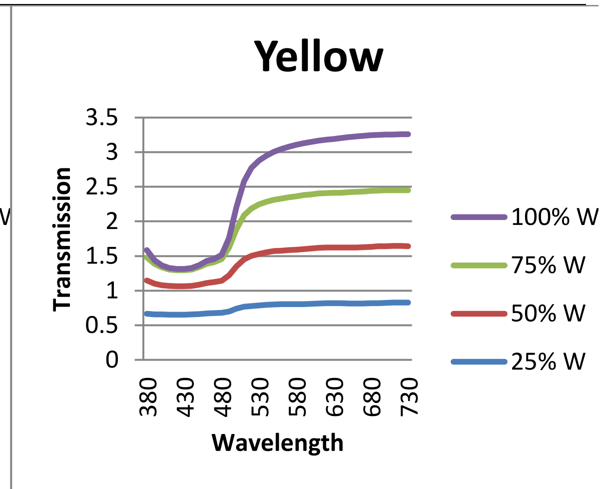

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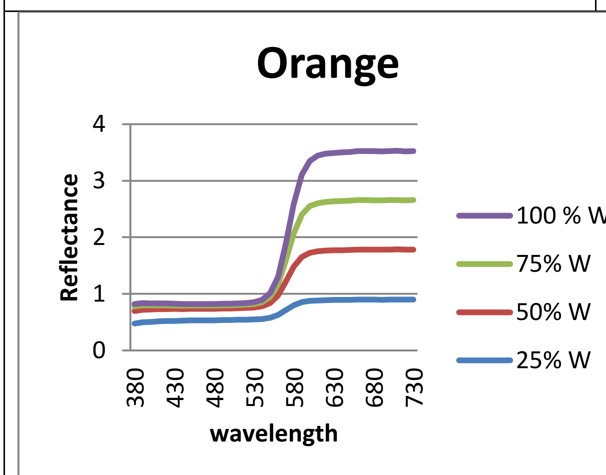

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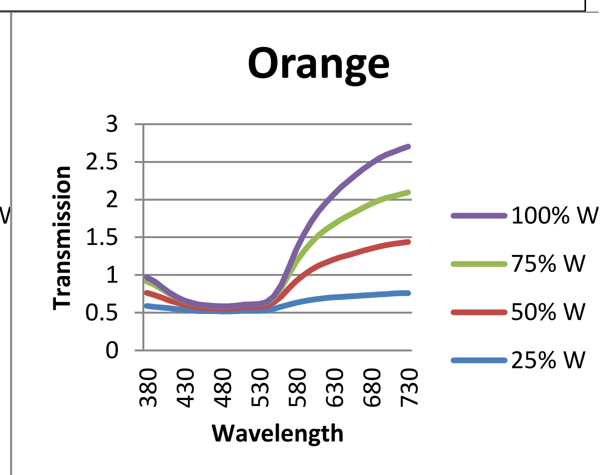

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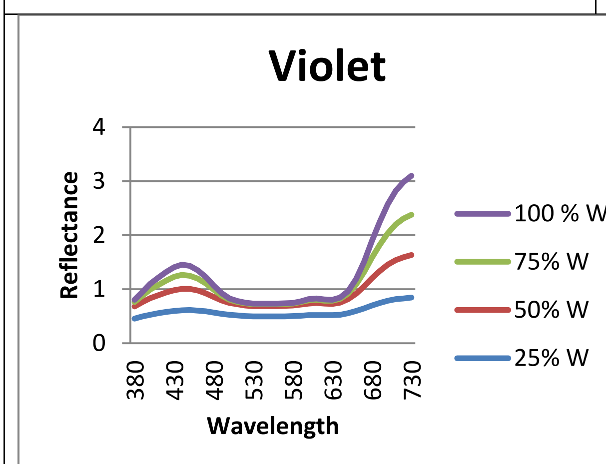

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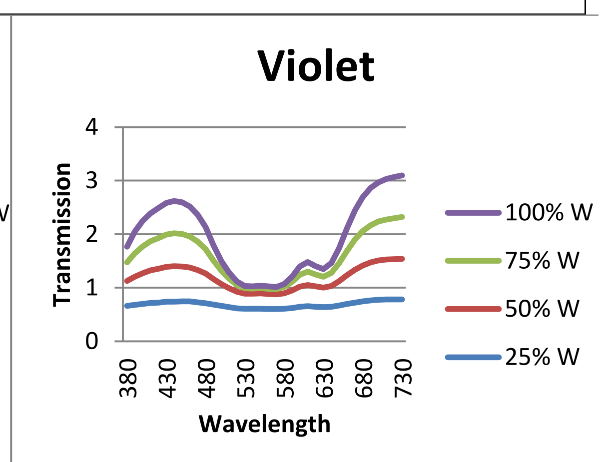

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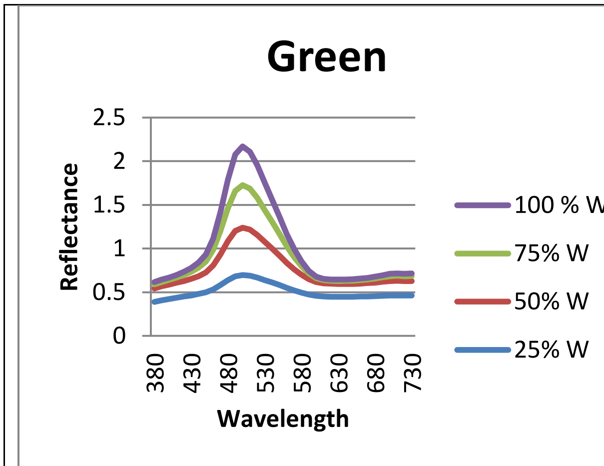
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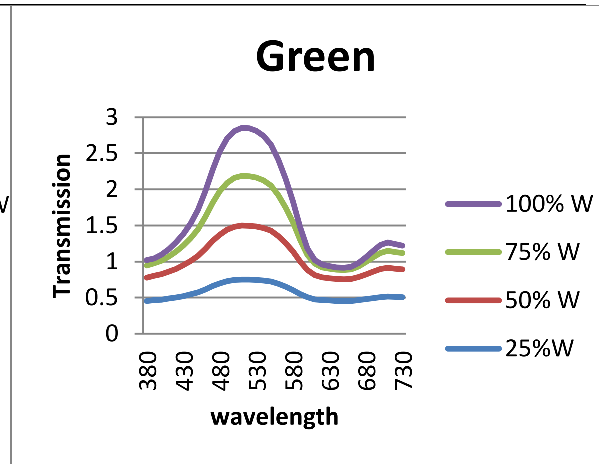
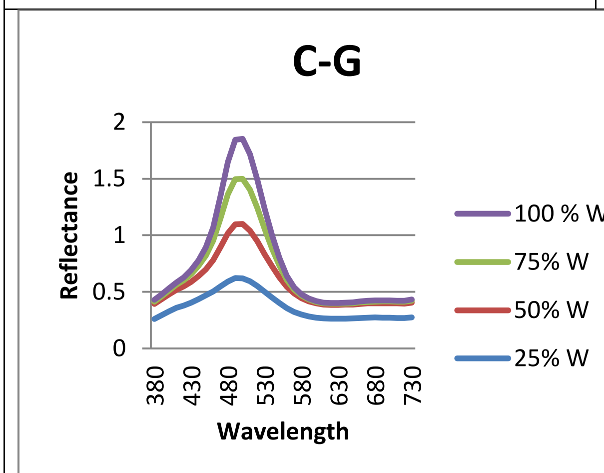
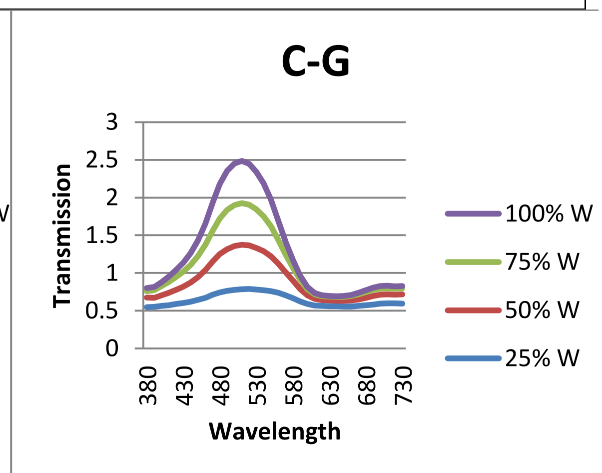
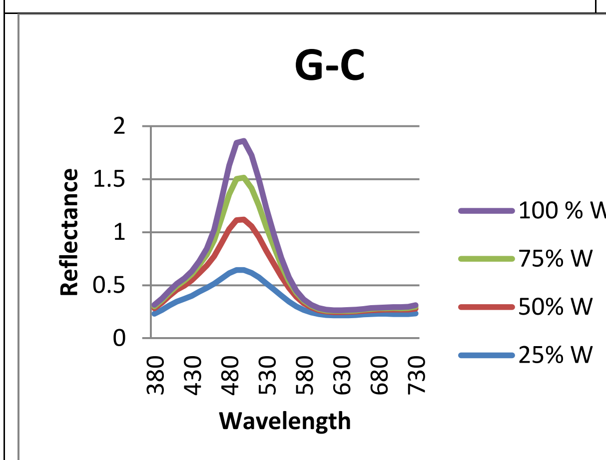
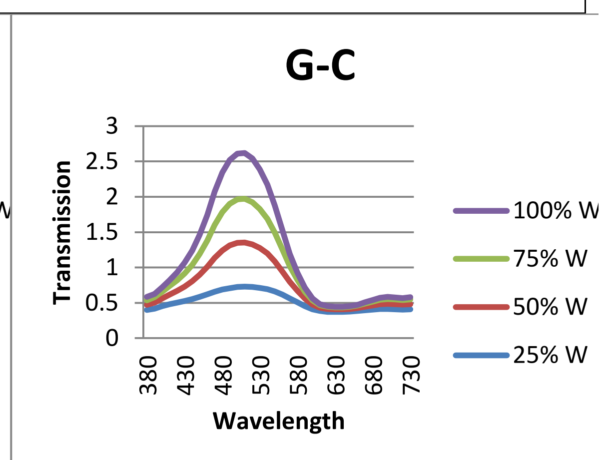
50% W
25% W

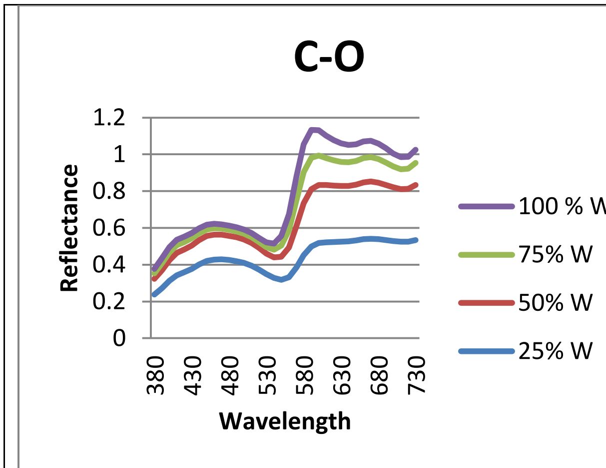

Green
Transmission
3
2.5
2
1.5
1
0.5
0
380
430
480
530
580
630
680
730
wavelength
100% W
75% W
50% W
25%W

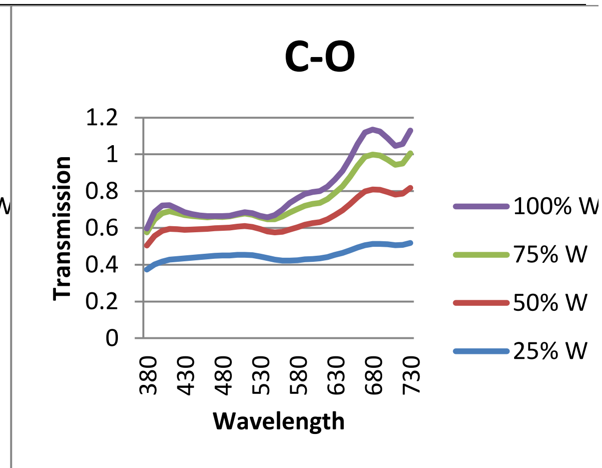

C-G
Reflectance
2
1.5
1
0.5
0
380
430
480
530
580
630
680
730
Wavelength
100 % W
75% W
50% W
25% W

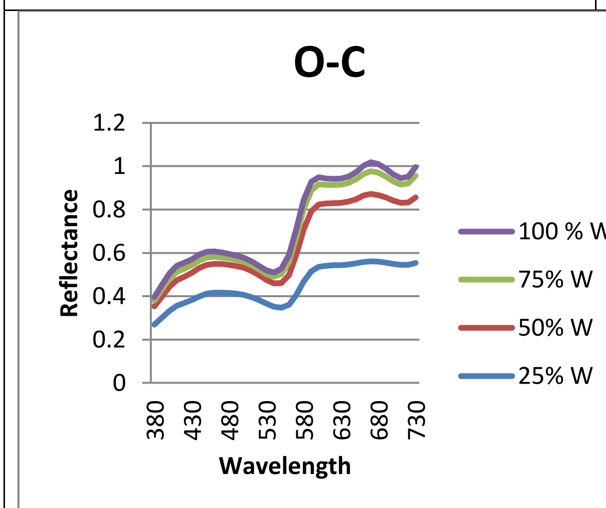

C-G
Transmission
3
2.5
2
1.5
1
0.5
0
380
430
480
530
580
630
680
730
Wavelength
100% W
75% W
50% W
25% W

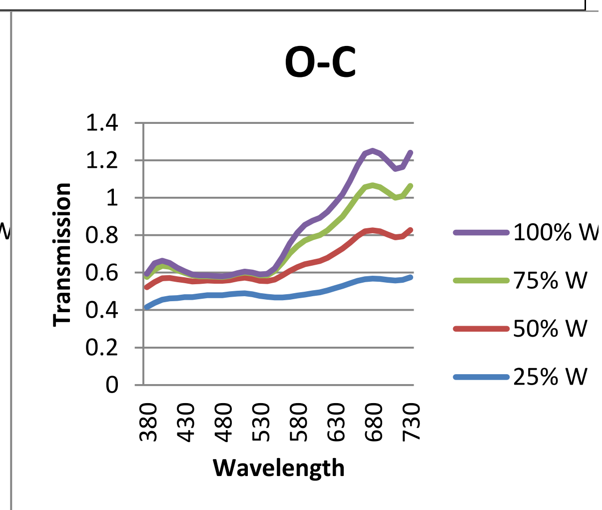

G-C
Reflectance
2
1.5
1
0.5
0
380
430
480
530
580
630
680
730
Wavelength
100 % W
75% W
50% W
25% W

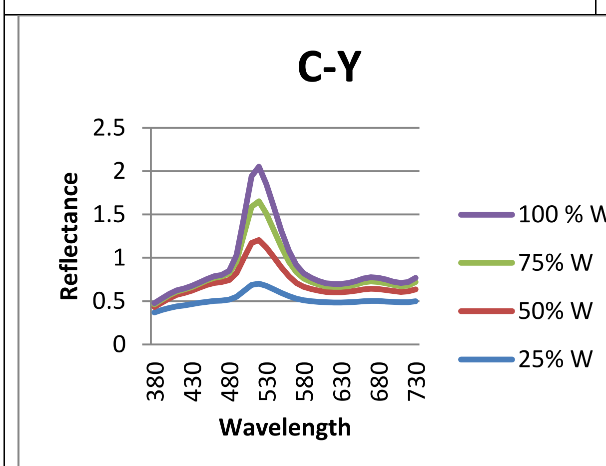

G-C
Transmission
3
2.5
2
1.5
1
0.5
0
380
430
480
530
580
630
680
730
Wavelength
100% W
75% W
50% W
25% W

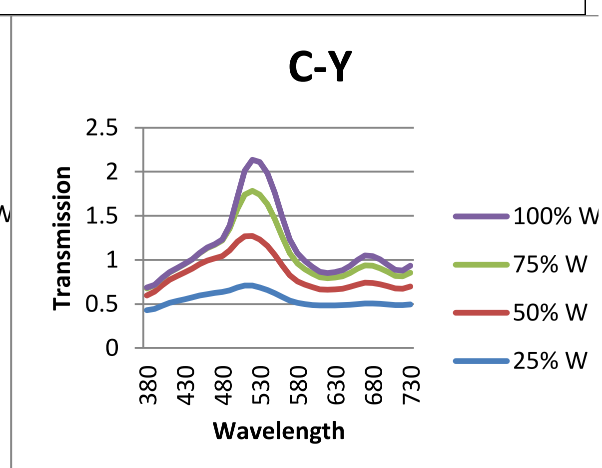

C-O
Reflectance
1.2
1
0.8
0.6
0.4
0.2
0
380
430
480
530
580
630
680
730
Wavelength
100 % W
75% W
50% W
25% W

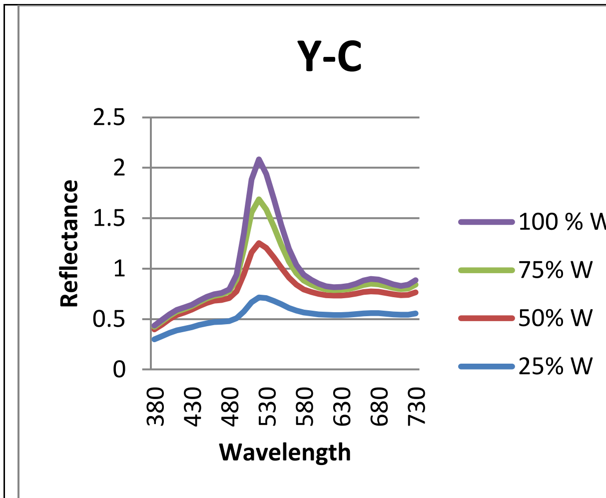

C-O
Transmission
1.2
1
0.8
0.6
0.4
0.2
0
380
430
480
530
580
630
680
730
Wavelength
100% W
75% W
50% W
25% W

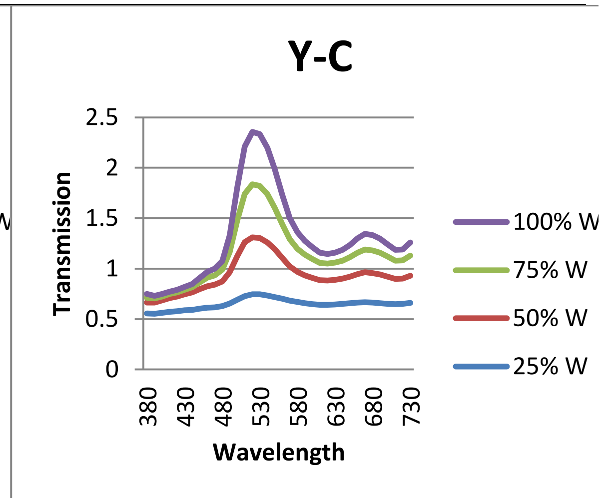

O-C
Reflectance
1.2
1
0.8
0.6
0.4
0.2
0
380
430
480
530
580
630
680
730
Wavelength
100 % W
75% W
50% W
25% W

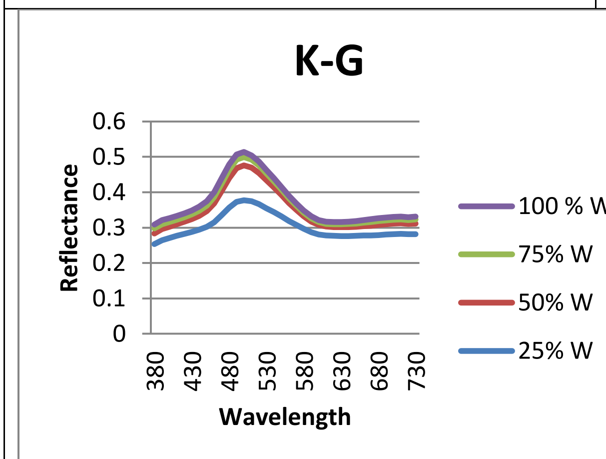

O-C
Transmission
1.4
1.2
1
0.8
0.6
0.4
0.2
0
380
430
480
530
580
630
680
730
Wavelength
100% W
75% W
50% W
25% W

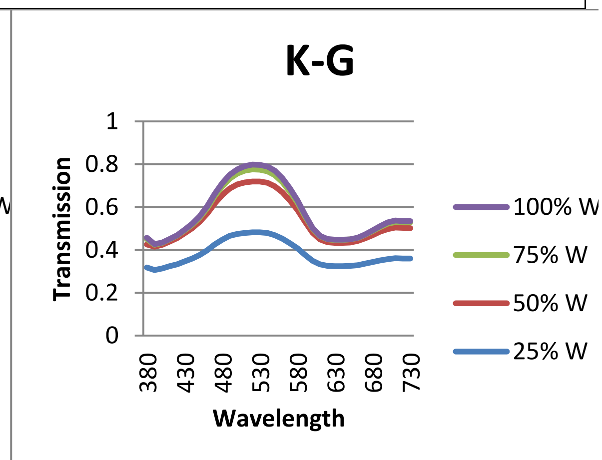

C-Y
Reflectance
2.5
2
1.5
1
0.5
0
380
430
480
530
580
630
680
730
Wavelength
100 % W
75% W
50% W
25% W

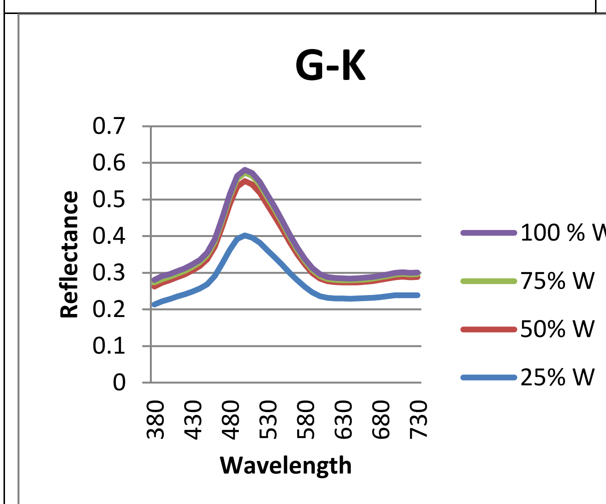

C-Y
Transmission
2.5
2
1.5
1
0.5
0
380
430
480
530
580
630
680
730
Wavelength
100% W
75% W
50% W
25% W

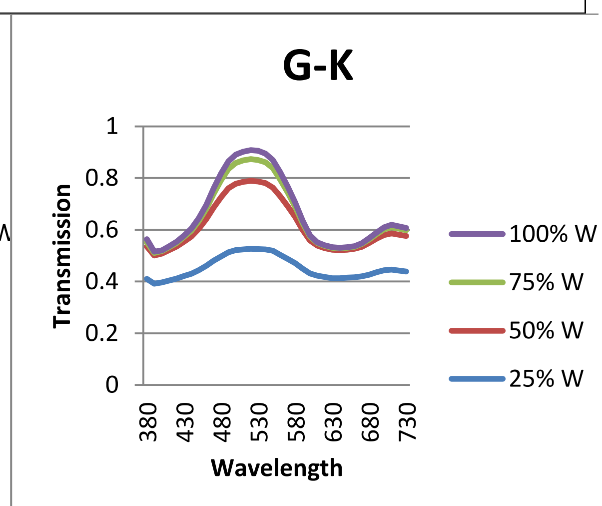

Y-C
Reflectance
2.5 2 1.5 1 0.5 0
380 430 480 530 580 630 680 730
Wavelength
100 % W
75% W
50% W
25% W

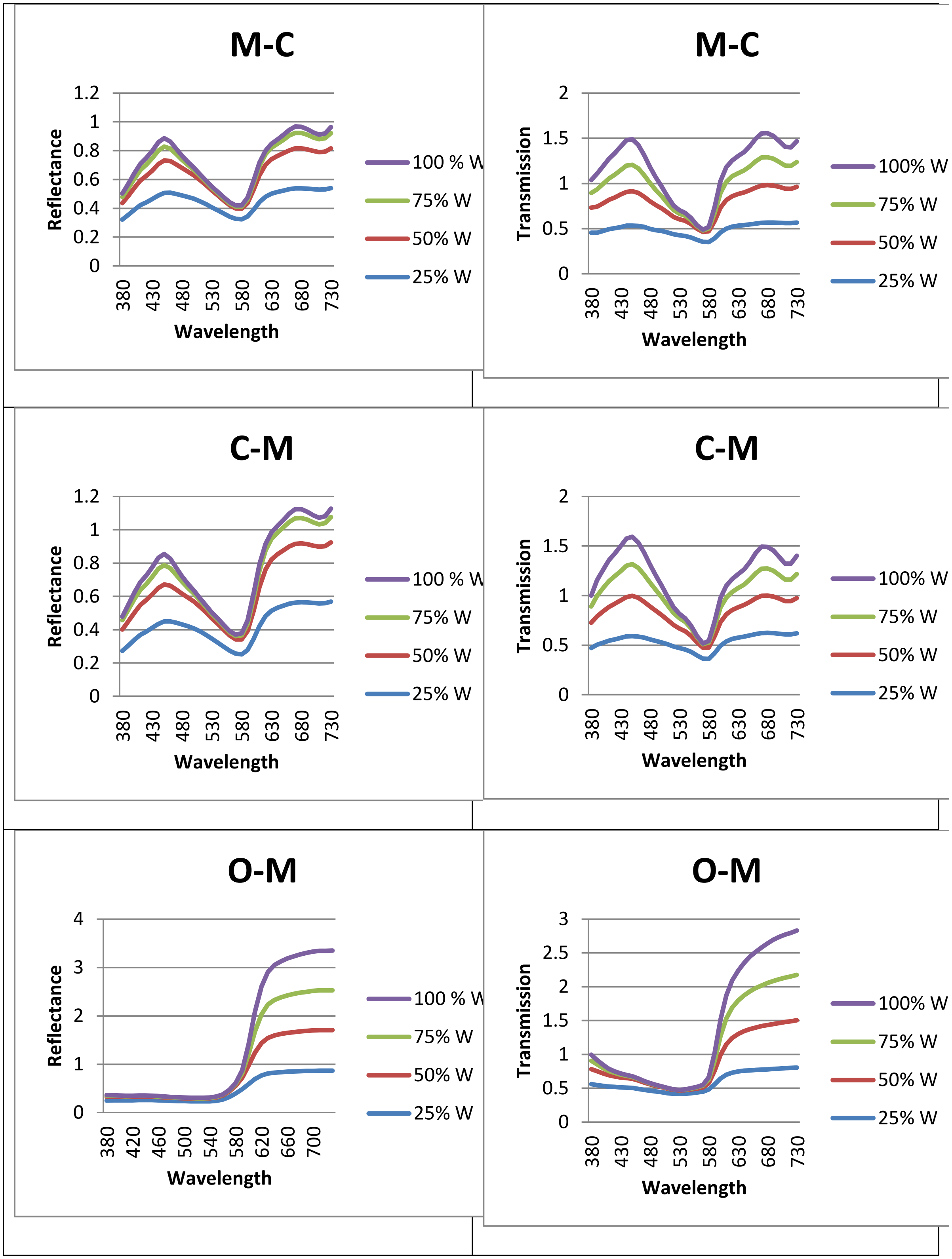

Y-C
Transmission
2.5 2 1.5 1 0.5 0
380 430 480 530 580 630 680 730
Wavelength
100% W
75% W
50% W
25% W

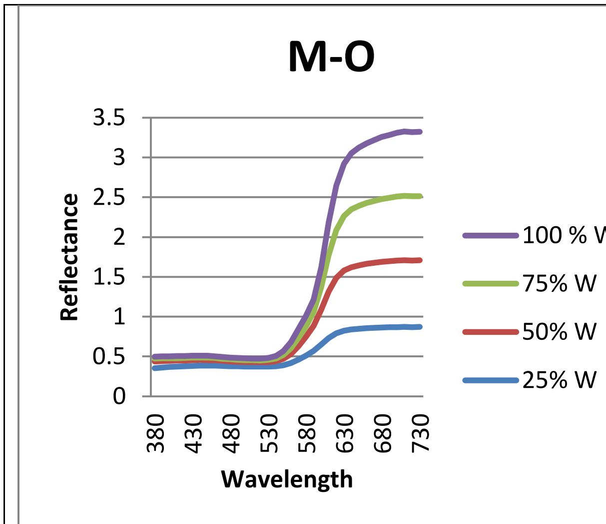

K-G
Reflectance
0.6 0.5 0.4 0.3 0.2 0.1 0
380 430 480 530 580 630 680 730
Wavelength
100 % W
75% W
50% W
25% W

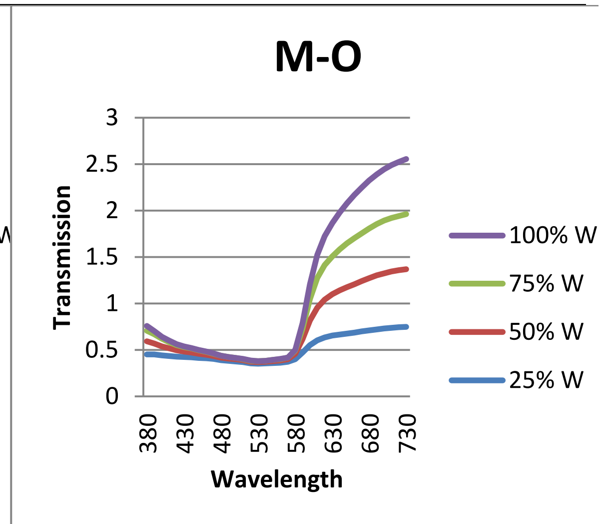

K-G
Transmission
1 0.8 0.6 0.4 0.2 0
380 430 480 530 580 630 680 730
Wavelength
100% W
75% W
50% W
25% W

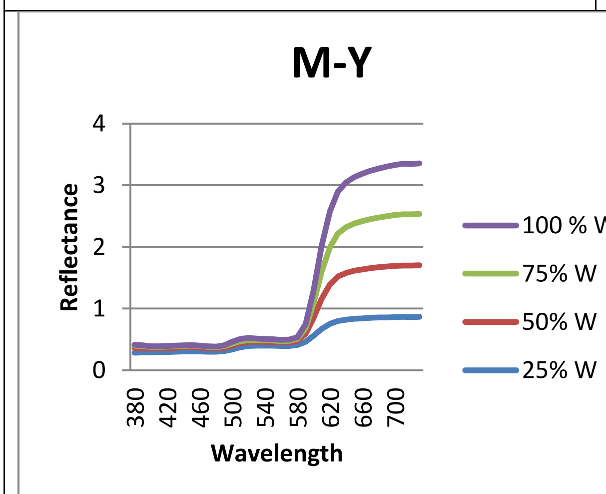

G-K
Reflectance
0.7 0.6 0.5 0.4 0.3 0.2 0.1 0
380 430 480 530 580 630 680 730
Wavelength
100 % W
75% W
50% W
25% W

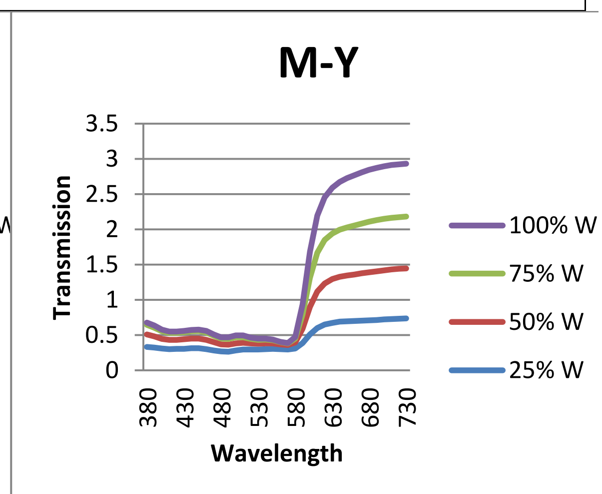

G-K
Transmission
1 0.8 0.6 0.4 0.2 0
380 430 480 530 580 630 680 730
Wavelength
100% W
75% W
50% W
25% W

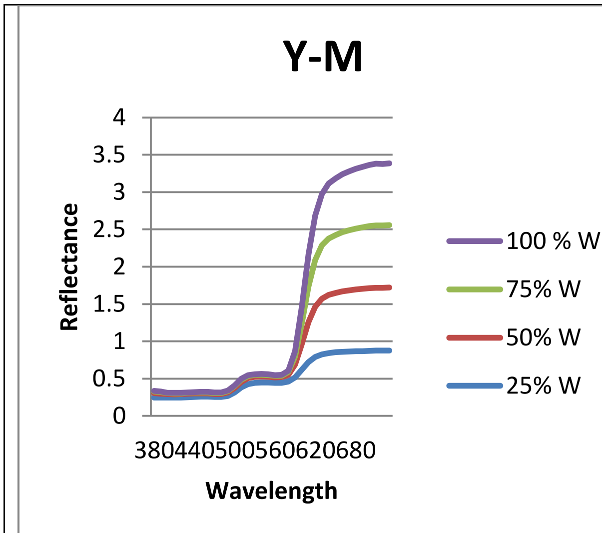

M-C
Reflectance
Wavelength
100 % W
75% W
50% W
25% W
M-C
Transmission
Wavelength
100% W
75% W
50% W
25% W
C-M
Reflectance
Wavelength
100 % W
75% W
50% W
25% W
C-M
Transmission
Wavelength
100% W
75% W
50% W
25% W
O-M
Reflectance
Wavelength
100 % W
75% W
50% W
25% W
O-M
Transmission
Wavelength
100% W
75% W
50% W
25% W

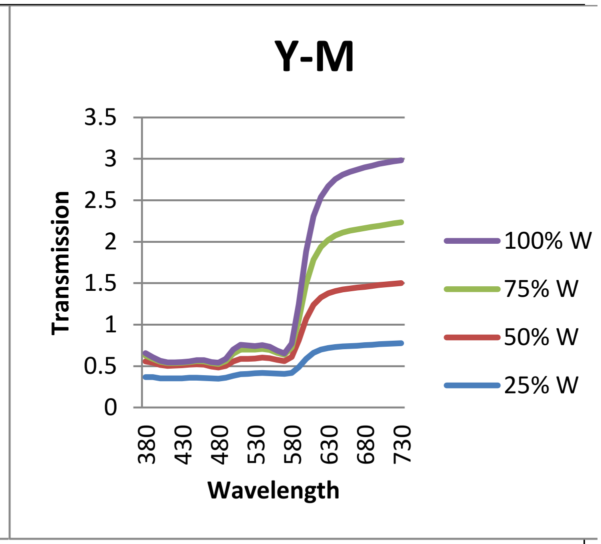

M-O
Reflectance
0
0.5
1
1.5
2
2.5
3
3.5
380
430
480
530
580
630
680
730
Wavelength
100 % W
75% W
50% W
25% W

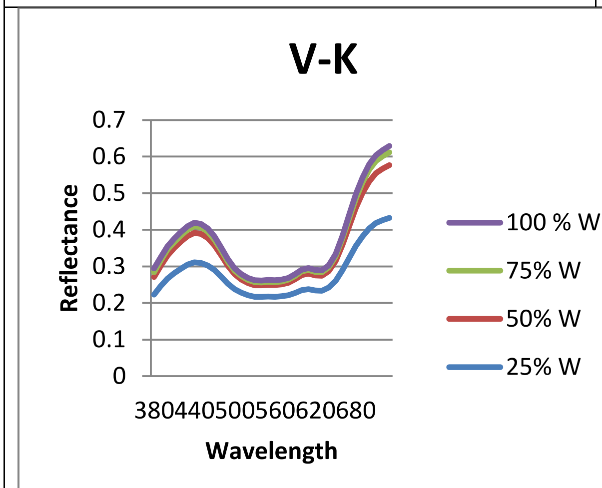

M-O
Transmission
0
0.5
1
1.5
2
2.5
3
380
430
480
530
580
630
680
730
Wavelength
100% W
75% W
50% W
25% W

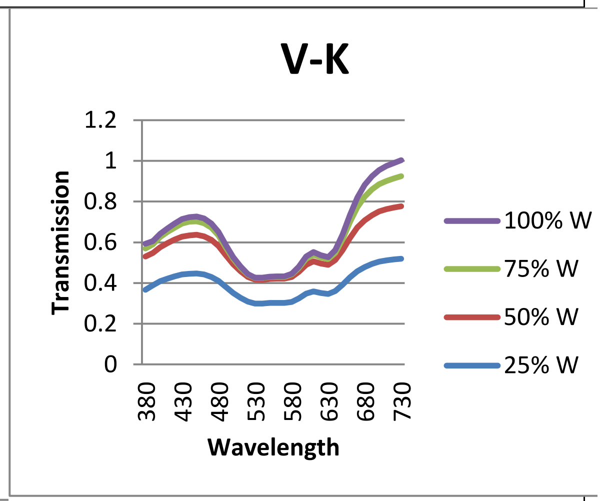

M-Y
Reflectance
0
1
2
3
4
380
420
460
500
540
580
620
660
700
Wavelength
100 % W
75% W
50% W
25% W

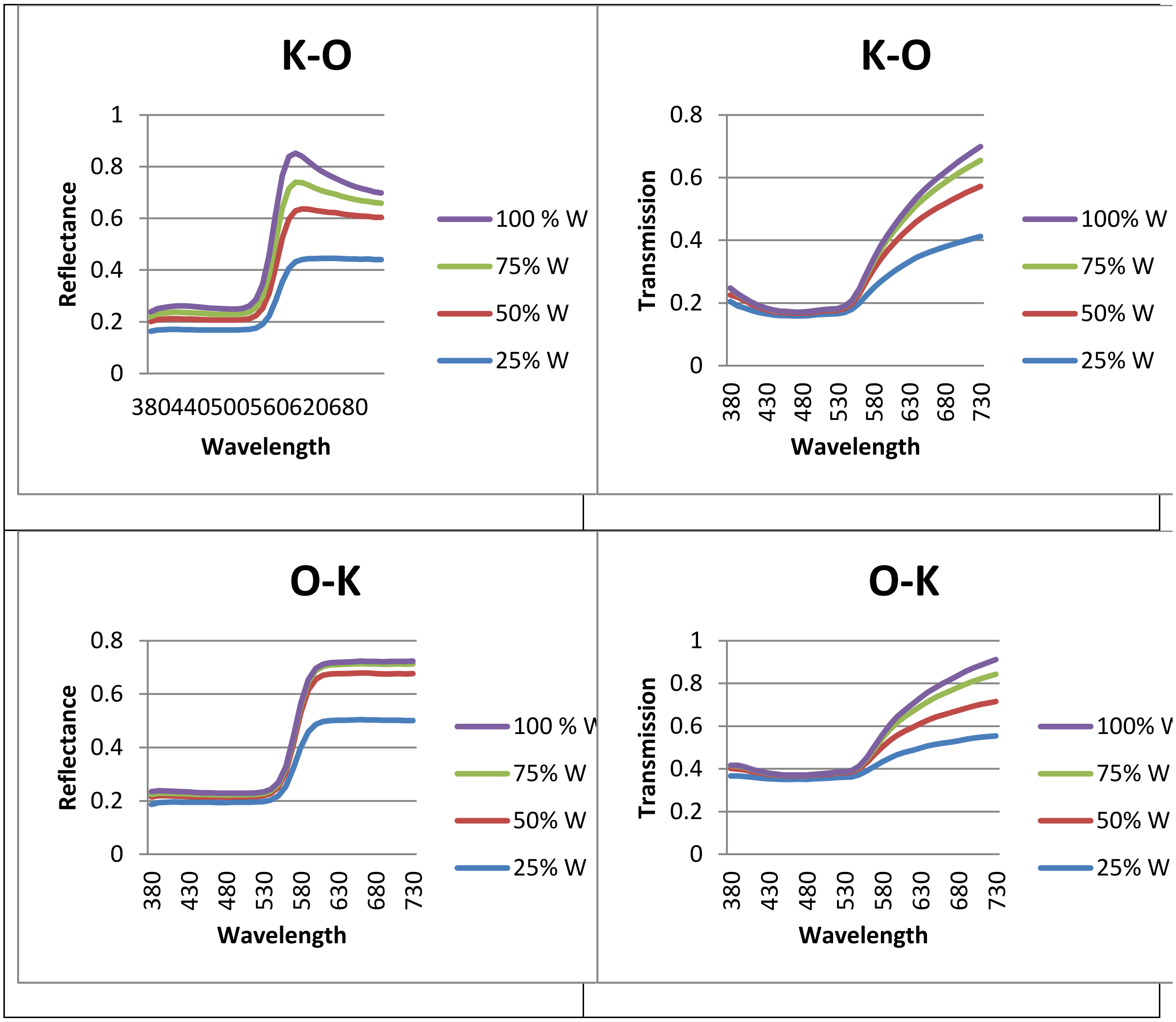

M-Y
Transmission
0
0.5
1
1.5
2
2.5
3
3.5
380
430
480
530
580
630
680
730
Wavelength
100% W
75% W
50% W
25% W

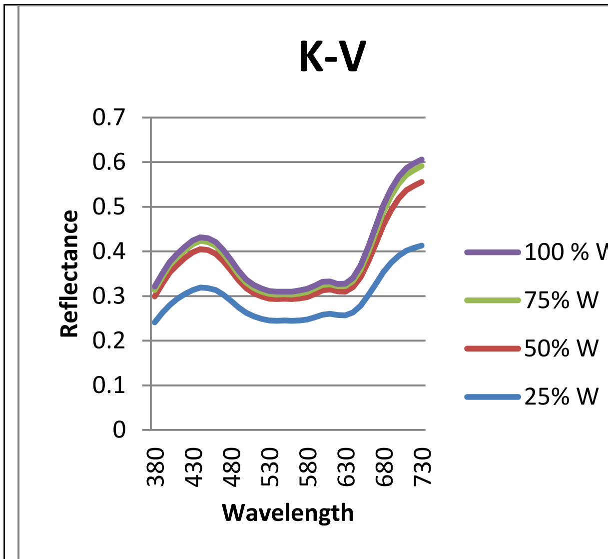

Y-M
Reflectance
4
3.5
3
2.5
2
1.5
1
0.5
0
380440500560620680
Wavelength
100 % W
75% W
50% W
25% W


Y-M
Transmission
3.5
3
2.5
2
1.5
1
0.5
0
380
430
480
530
580
630
680
730
Wavelength
100% W
75% W
50% W
25% W


V-K
Reflectance
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
380440500560620680
Wavelength
100 % W
75% W
50% W
25% W


V-K
Transmission
1.2
1
0.8
0.6
0.4
0.2
0
380
430
480
530
580
630
680
730
Wavelength
100% W
75% W
50% W
25% W


K-O
Reflectance
1
0.8
0.6
0.4
0.2
0
380440500560620680
Wavelength
100 % W
75% W
50% W
25% W
K-O
Transmission
0.8
0.6
0.4
0.2
0
380 430 480 530 580 630 680 730
Wavelength
100% W
75% W
50% W
25% W
O-K
Reflectance
0.8
0.6
0.4
0.2
0
380 430 480 530 580 630 680 730
Wavelength
100 %
75% W
50% W
25% W
O-K
Transmission
1
0.8
0.6
0.4
0.2
0
380 430 480 530 580 630 680 730
Wavelength
100%
75% W
50% W
25% W



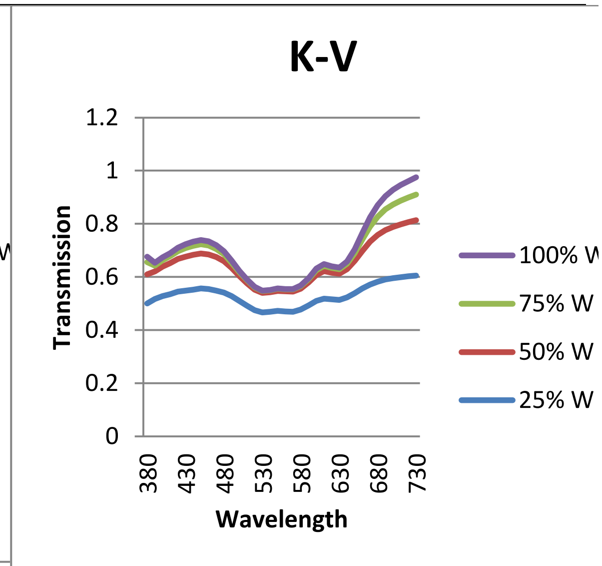


Figure 22: Spectral Reflectance Curves	Figure 23: Spectral Transmission Curves

General Regression Analysis: Opacity by transparency versus Opacity

Regression Equation

Opacity by Transparency = 3.10199 + 0.983184 Opacity by Reflection

Coefficients

Term	Coef	SE Coef	T	P
Constant	3.10199	0.238584	13.002	0.000
Opacity	0.98318	0.007258	135.467	0.000

Summary of Model
S = 1.86531
R-Sq = 99.47%
R-Sq (adj) = 99.46%
R-Sq (pred) = 99.41%
PRESS = 378.686.

Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	1	63851	63851	63851	18351.2	0
Opacity	1	63851	63851	63851	18351.2	0
Error	98	341	341	3.5	64192	
Total	99					

Fits and Diagnostics for Unusual Observations

Obs	**O_T**	**Fit**	**SE Fit**	**Residual**	**St Residual**		
30	2.5494	12.491	0.202746	-9.9414	-5.36139	R	
65	92.2931	90.894	0.533016	1.3996	0.78295		X
79	99.3333	99.782	0.594923	-0.4484	-0.25365		X
85	76.3665	89.262	0.521750	-12.8954	-7.20067	R	
88	91.4298	90.045	0.527151	1.3850	0.80373		X
89	94.9574	92.530	0.544348	2.4275	1.36064		X
90	98.1252	100.560	0.600382	-2.4351	-1.37885		X
91	94.3043	92.871	0.546714	1.4334	0.80373		X
96	87.2466	85.932	0.498871	1.3147	0.73145		X
98	83.5556	82.303	0.474131	1.2526	0.69434		X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.