The Effect of Ink Film Thickness Variations on Color Control in the Circumferential Printing Cylinder Direction of Offset Presses

Manfred H. Breede*

Keywords: Ink feed control, Color variation

Abstract: The inking system of an offset press moves ink from a reservoir (ink fountain) to the printing plate by metering a thick charge of ink which has to be thinned into an ink film that produces acceptable print quality by upward of ten rollers because of the high viscosity of offset inks. Moreover, the amounts of ink that has to be dispensed from the ink fountain varies in every ink zone or in the axial direction of a printing cylinder, in accordance with image area content, which can vary from no image areas at all to solid areas and every conceivable tonal area in between.

Because the rollers (form rollers) at the end of the ink train, which apply the ink to the printing plate, have diameters that are much smaller than that of the printing cylinder, they must necessarily make several revolution to cover the distance from the leading to the trailing edge of an image area, which is problematic, as the initial thick charge of ink must be metered in such a way that all image areas in the circumferential direction of the print form receive uniform amounts of ink. We know from practical experience that this is not totally possible and must therefore accept a somewhat unequal ink film thickness in the circumferential direction of the printing cylinder as an inherent limitation of the offset lithographic inking system.

The control of ink film thickness is effected in one of two ways, 1, varying the thickness of the ink film in individual zones by means of so-called ink keys, and 2, increasing the overall charge of ink by varying the sweep of the fountain roller.

Because there is no practical method of controlling ink film thickness in the circumferential direction of the printing cylinder print quality is unpredictable in the areas that are located in the path of an ink film thickness adjustment zone.

---

*Ryerson University, School of Graphic Communications Management.

The hypothesis of the study is that ink film adjustments in given zones affect tonal areas from shadows to highlights differently and that the inherent weaknesses of offset lithographic inking systems results in a somewhat unpredictable print quality.

A test form was designed to make spectral measurements of varying tonal areas in identical ink zones possible. This was done for the three primary colors and their secondary color composites.

An experimental press run was conducted, by means of which the ink film thickness was varied from a normal ink film thickness to three more incrementally decreased levels ink film thickness.

The results of the study will show ΔE_{ab} color variations caused by ink film thickness changes in ten tonal areas.

1. Introduction

The ultimate goal of all printing processes with the possible exception of gravure and in some circumstances digital printing, is to deposit a uniformly thick ink film in all image areas, because tonal differences are created not by varying the amount of ink, but by the size of dots that produce the optical illusion of tonal variation.

Flexography uses relatively fluid inks, which can be transferred from an ink reservoir to the substrates by a very short ink train consisting of only one roller (anilox roll). Once a given contact area of the anilox roll transfers ink to the printing plate it will not again come into contact with other image areas of the printing plate until it returns to the ink reservoir to be replenished with the exact same amount of ink. This method of ink feed makes zonal ink control unnecessary, and at the same time assures a uniform ink film thickness in all areas of the printed image.

In gravure, the metering of very fluid inks is a function of variable depths of image elements themselves, which as such requires only the leveling and scraping of ink from the non image areas by means of a blade (doctor blade).

Screen printing achieves ink film thickness uniformity by the levelness and uniform pressure of a squeegee

In digital printing devices the amount of colorant (ink or toner) can be controlled for the smallest discrete image element (pixel or spot) because a direct electronic link between the imaging element and the digital image file exists, which does not preclude the option of varying the amounts of colorant at discrete image locations.

What sets the offset lithographic and letterpress printing processes apart from the foregoing printing processes is that they must feed unequal amounts of ink in the axial direction of the printing cylinder in order to achieve uniform ink film thickness on the substrate printed. The primary reason for this apparent paradox is related to the paste-like viscosity of the inks used for these printing processes, which can not be transferred via a short ink train such as the anilox roll system in flexography for example.

The offset lithographic printing process mandates an inking system that has upward of ten rollers to transfer the ink from a reservoir to the substrate, because the high viscosity inks used in offset lithography resist flow (Figure 1). Depending on the image composition to be printed in a given axial direction of the printing cylinder, the ink film thickness dispensed from the ink reservoir (ink fountain) is in a range of 50 to 250 microns (MacPhee, 1998). Repeated kneading of the ink as it passes through the nips of alternating soft and hard rollers (Figure 1) reduces its viscosity as well as progressively thins the ink film, because at every roller nip the ink film is split approximately 50%. Once applied to the blanket cylinder the ink film thickness is reduced to approximately 2 microns and after its final transfer to the substrate it measures approximately 1 micron on coated paper (MacPhee, 1998) which is further corroborated by Dąbrowa and Gajadhur, (2006) who found that an ink film thickness of 1.2 microns produce a maximum number of reproducible colors.

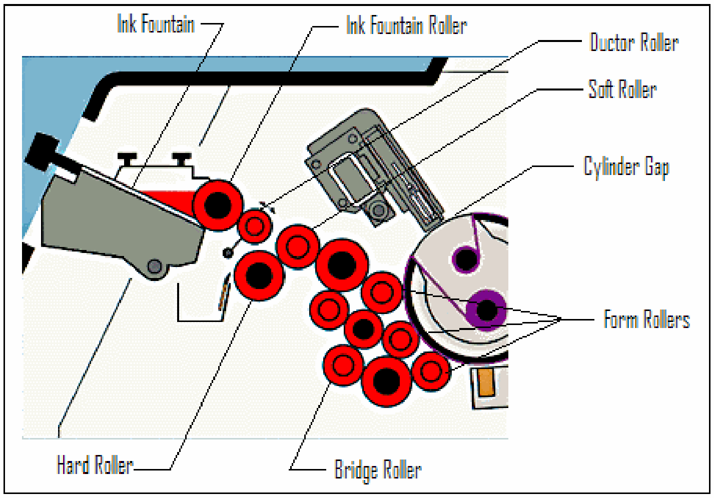


Figure 1.
Offset lithographic ink train (waterless).

Because ink film variations as small as 0.1 microns (MacPhee, 1998) is noticeable to the human eye, ink film thickness uniformity is both a technical inking system design challenge and a print production issue.

2. Factors contributing to ink film thickness variations

Disruptive factors that cause an ink film to be unevenly thick are principally attributable to 1, press and inking system design and 2, image configuration.

2.1. Press and Inking System Design Factors

Several inherent design features of the offset lithographic press in general and the inking system of such presses in particular, can produce unevenly thick ink films, ranging from barely noticeable to unacceptable. This is to say; even the best inking system design will cause some ink film thickness variations, albeit perceptibility may be so minor as to be negligible.

Because ink metering occurs intermittently once for every two printing cylinder revolutions by means of a swinging ductor roller (Figure 1), the stripe of ink film dispensed from the ink fountain roller is extremely thick. Although multiple rollers of the inking system distribute and thin the ink film by virtue of the aforementioned 50/50 ink film split principle, it is still possible that this discontinuous ink feed could cause cyclical surges of ink and subsequent ink film thickness variation on the substrate.

Sheet-fed presses have plate cylinders with gaps (Figure 1) in the circumferential direction of the plate cylinder in order to fit the plate fastening and tensioning mechanisms. These gaps could occupy upward of a fifth of the circumference of the cylinder and are necessarily an ink free area, which could cause an oversupply of ink in those parts of an image area, which are inked immediately after the rollers have passed this ink free cylinder gap.

The form rollers which transfer ink to the printing plate have a circumference which is about one third the length of the circumferential image length (Figure 1), which means that these rollers have to make three revolutions to cover the circumferential image length of the plate. Consequently, the aforementioned ink supply surges could cause repeated patterns of low and high ink film thickness with each revolution of the form rollers.

2.2. Image Configuration Factors

An ideal ink metering system should be capable of supplying ink that will result in a uniform ink film thickness independent of the infinitely variable image combinations that are possible in images to be reproduced. Given the constrains imposed by moving a viscous liquid via a relatively long ink roller train there are certain image configurations that are problematic with regard to ink film thickness uniformity. The axial direction of an offset lithographic inking system is divided into approximately 1.5 inch wide ink zones. At the source of the ink (ink fountain), an amount of ink corresponding to the circumferential image area percentage of a given zone is dispensed to the roller train. If, for example two juxtaposed solid image areas, one having 100% and the other having 10% circumferential image areas, the 10% image area will be affected by an oversupply of ink from the neighboring 100% image area by virtue of the fact that liquids cannot be confined accurately in their respective zones. This problem is further compounded by so called vibrator rollers in the roller train, which have to make oscillating or sideward movements in order to prevent the formation ink ribs which could cause circumferential streaks on the substrate to be printed (MacPhee, 1998).

Another source for ink film thickness variations are image areas that repeat themselves as darker or lighter ghost images onto other image areas in their circumferential path. This problem is called mechanical ghosting. One possible scenario is when a reverse shape or negative image is in the circumferential path of a solid area. This causes a slightly darker ghost image of the negative shape in the circumferential path of the solid. The opposite scenario is when a shape or bold line of text is in the circumferential path of a solid, which causes the solid to have a ghost image of the offending shape, which is slightly lighter than the surrounding solid area. Mechanical ghosting is essentially caused by a rupture in the ink film on the form rollers subsequent to transferring ink to the printing plate. Since the form rollers have to make multiple revolutions across the image area, the ink film rupture causes a localized oversupply of ink as described in the first scenario above, or a localized undersupply as described in the second scenario.

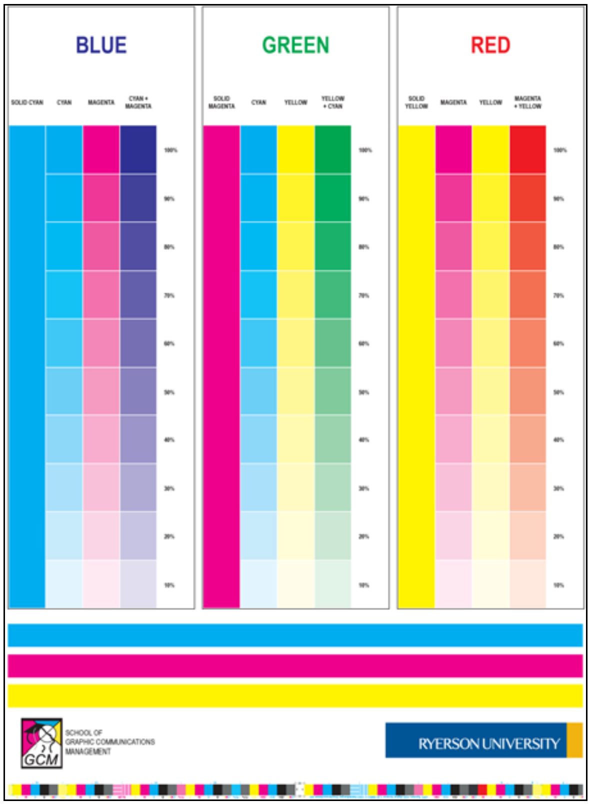
In general, fitting extra rollers (rider and bridge rollers) in an inking system (Figure 1), especially in the lower parts of the ink train where mechanical ghosting is transferred to the plate, attenuates mechanical ghosting, because every additional nip point decreases the unevenness in ink film thickness by approximately 50%, which means ink film variations are reduced, but never completely eliminated. Additionally, variable diameter form rollers that deliver the great majority of ink via the first form roller; prevent ghost images to be accentuated.

With these inherent offset lithographic inking system limitations in mind, in this study, the potential negative effects on the reproduction of color will be investigated.

3. Experimental

The general aim was to print a custom designed test form (Figure 2) consisting of cyan, magenta, yellow solid and tint screen image bands, as well as the resulting red, green and blue overprint bands at normal and incrementally diminishing ink levels.

-Leading Edge-



-Trailing Edge-

Figure 2.
Test form

Subsequent to achieving solid ink densities that approach GRACoL specifications (2002) the ink feed was decreased three consecutive times by repeatedly lowering the sweep of the doctor and fountain rollers.

Both optical density and CIELAB values were recorded for each measurement simultaneously on four samples, representing different levels of ink feed.

Solid C,M,Y image bands measuring 10.375 inches in circumferential length were measured ten times at the approximately position of adjacent ten tonal-step halftone dot patches (10% increments from solid to 10%). These measurements established the uniformity of ink film thickness, or lack thereof, in the circumferential image direction, as well as the colorimetric effects of ink film thickness variations.

Likewise ten C.M,Y and R,G,B tonal steps varying incrementally by 10% in the circumferential image direction were measured. These measurements established the colorimetric effects of ink film variations in a given ink zone for the entire tonal range from 10 to 100%.

The test form was printed on a Heidelberg Quickmaster DI, four color-units, waterless offset press. The ink train of this press is temperature controlled and consists of 11 rollers, excluding the fountain roller (Figure 1). The inking unit has 3 variable diameter form rollers with an ink flow of 88%, 8%, 4% via the first, second and third form roller respectively.

The substrate printed was an 148 g/m^2, M-Real, Euro, Art Gloss DI, coated offset paper. The inks used, were waterless inks by Rycoline and the lay down sequence was C, M, Y.

All measurements were made with an X-Rite 530 spectrodensitometer (Status T filters). The instrument was programmed to read CIELAB values using the 10° Observer and D50 illuminant.

4. Methodology

The press sheet representing normal ink feed served as the standard against which each of the three samples with continuously diminishing ink feed were compared. Every patch measured on the standard was compared to a spatially equivalent patch of the samples. Ink film thickness was inferred from optical densities and colorimetric differences between the standard and a sample were expressed in ΔE_{ab} units.

Since each image band is located in a discrete ink zone which is controlled by a single ink fountain key, selective ink feed control in the circumferential direction of the image band is not possible, which implies that ink film thickness variations and consequential color variations in the circumferential direction of the solid image bands must necessarily be caused by the ink train itself and/or the image composition.

Because the test form's image composition of the solid image bands is continuous and nearly continuous in the halftone wedges, significant ink film thickness variations due to mechanical ghosting can probably be ruled out. This leaves the ink unit and printing press design as the most probable cause for ink film thickness variation in the circumferential image direction.

5. Results and Discussion

Given that it has been shown that optical densities have a reasonably good correlation with ink film thickness (Field, 1999), (Dąbrowa and Gajadhur, 2006) optical densities will be used to infer ink film thickness uniformity in the circumferential cylinder direction.

5.1 Ink Film Thickness Unevenness

The normal ink feed sample's cyan, magenta and yellow solid ink optical densities, when measured at 1 inch intervals from the trailing edge to the lead edge, clearly indicate uneven ink film application. However, more significantly, these variations are not randomly distributed, but occur in cyclical patterns, which in all likelihood stems from the aforementioned inability of an offset lithographic inking system to supply constant amounts of ink (Figure 3).

The calculated difference between the highest and the lowest density values or ranges for cyan, magenta and yellow were 0.13, 0.08 and 0.05 respectively.

In order to determine the relative significance of these results, a supplementary print run, using a printing process which is not subject to the same technical limitations as an offset lithographic press, was conducted. Therefore, the same digital file as the one used for the offset print run, was again printed on an HP Color LaserJet 9500 HDN digital press. The last sheet of 100 sheets printed was measured as previously (Figure 4).

The calculate ranges for this test run were 0.06, 0.10 and 0.05 for cyan, magenta and yellow respectively. While these values are not significantly different from the offset test run, the distribution of data points are somewhat more abrupt and sporadic as opposed to cyclical. This leads one to conclude that digital printing devices are subject to similar variation in terms of ink film thickness minima and maxima, but that the causes thereof are related to factors distinctly different from those of an offset presses.

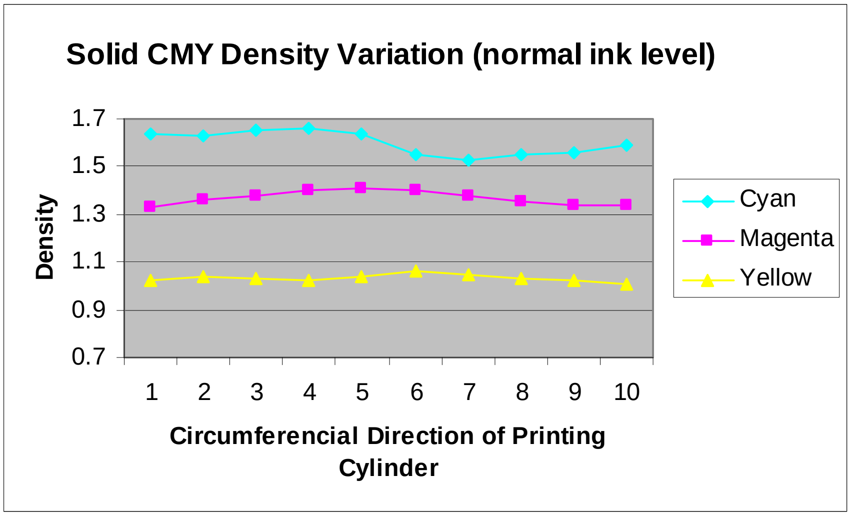


Figure 3
Solid ink density variation in the circumferential direction of the printing cylinder (offset).

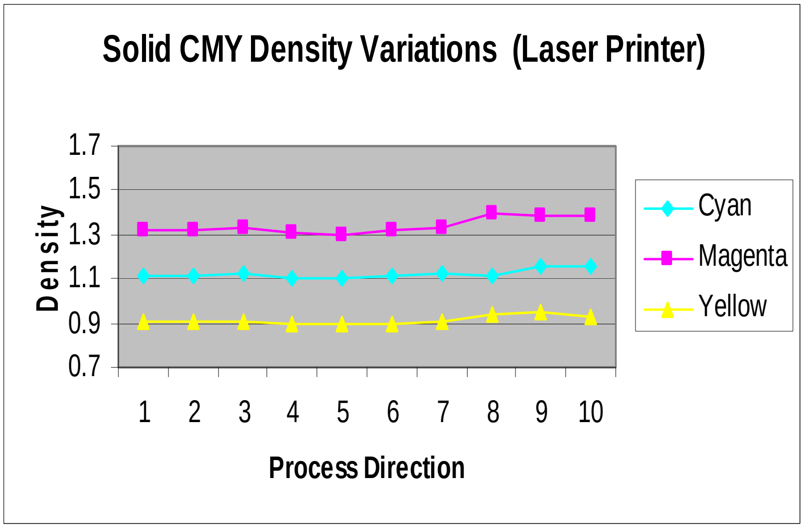


Figure 4.
Solid ink density variation in the circumferential direction of the printing cylinder (electrophotography).

The unevenness of ink films in offset lithographic inking systems was investigated by Rech (undated). He proposes in a paper and again in an abbreviated version (Kipphan, 2001) an ink film unevenness index which he calls “Ungleichförmigkeitsgrad” or Degree of Unevenness. Accordingly, the “Degree of Unevenness” is defined as follows:

$$\eta = \frac{S_{max} - S_{min}}{S_{average}} * 100\% \qquad (1)$$

Where:

η = Degree of Unevenness

S_{max} = the maximum ink film thickness on the plate printing elements,

S_{min} = the minimum ink film thickness on the plate printing elements,

$S_{average}$ = the arithmetic average of the ink film thickness of all printing plate elements.

Because Degree of Unevenness η places a marked emphasis on the extreme values of an ink film, which are naturally more likely to be noticed by an observer of a printed product, Rech considers the Degree of Unevenness to be the most important quality index.

Adopting the equation to solid ink density values, as measured on the substrate printed in this study yielded the following results:

Offset run:	Cyan	8.13%
	Magenta	4.37%
	Yellow	4.85%
	Sum	17.35
Laser printer run:	Cyan	5.36%
	Magenta	7.47%
	Yellow	5.46%
	Sum	18.29

Rech maintains in his paper that inking systems should aim for 3% Degrees of Unevenness, which was not quit achieved for neither the offset nor the digital press runs. Also seen in these results is that the sum of C,M,Y Degrees of Unevenness is, perhaps surprisingly, marginally lower in the offset run than in the laser printer run.

The colorimetric significance of these results when expressed in ΔE_{ab} units between the highest and the lowest optical density locations are 2.0, 2.5 and 3 for cyan, magenta and yellow respectively, which seems to indicate that yellow has the greatest sensitivity to ink film thickness variations, followed by magenta and cyan.

Therefore, on this specific press, these ΔE_{ab} values must be considered to be the maximum achievable color uniformity, along the length dimensions of the solid image bands of the test form, because there are no practical means to control ink film thickness in the circumferential direction of the printing cylinder.

Having established that ink film thickness variations in the circumferential directions of the printing cylinders do in fact occur, the extent to which it affects color appearance of different tonal areas could now be investigated.

5.1 The Colorimetric Effects of Ink Film Thickness in Ten Tonal Areas

Three samples with progressively decreasing amounts of ink were compared to a standard that was printed with normal ink feed. This was done in ten tonal areas ranging from a solid to a 10% image patch and recorded in ΔE_{ab} values. The results are shown in Figures 5.

Figure 5 shows ΔE_{ab} values of 10 tonal areas ranging from 10% to 100%, comparing a standard printed with normal amounts of ink with three samples printed with progressively reduced amounts of ink. Because the general tendencies were similar in all primary colors and secondary color overprints, Figure 5 shows the results of cyan only.

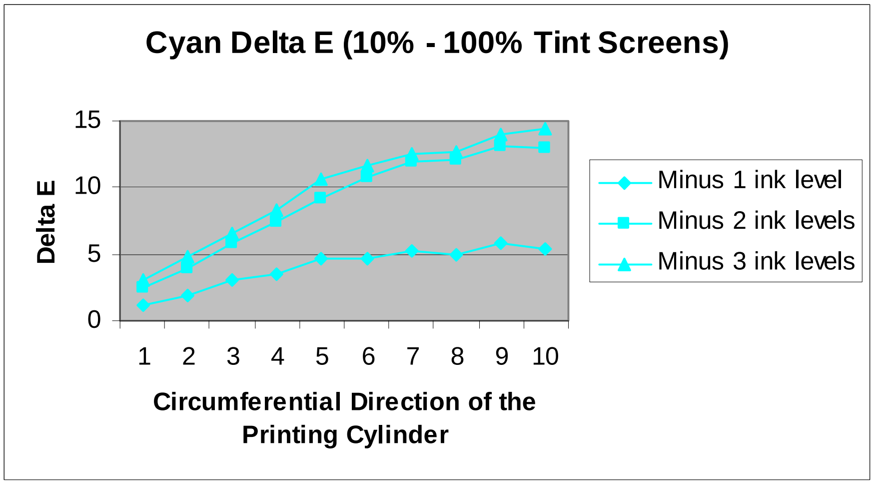


Figure 5
Cyan ΔE_{ab} values of ten tonal areas ranging from 10% to 100%, at 3 three ink levels.

Given that the measured tonal areas change equally at 10% increments throughout the tonal range, it should be expected that ΔE_{ab} values will have a perfectly linear correlation with ink film thickness if the ink film printed was also perfectly uniform. From earlier discussions we know that the offset lithographic inking system is inherently unable to produce a perfectly uniform ink film, which could explain the somewhat jaggedness of the three curves.

The more surprising finding of this study however, is that ΔE_{ab} values increase as tonal values become darker. This is especially pronounced, when the pressrun with normal amounts of ink is compared to the pressrun that has the lowest amount of ink. At the two opposite tonal extremes, ΔE_{ab} values of 3.1 and 14.4 were recorded for the 10% and 100% image patches respectively.

The practical implication of this finding is that the colorimetric effects of ink feed adjustments in a given ink zone will vary considerably depending on the darkness of the tonal area. If for example ink feed is changed on the basis of a 10% image area color assessment, a solid area which is in its circumferential path will experience a much greater color change than the 10% image area.

Even more significantly, ink flow measurements made on the basis of control strip measurements are relevant not only for the ink zone in which a given control strip patch is located, but also only for its equivalent tint screen value in the reproduced image. This is to say, the colorimetric change effected by an ink feed adjustment is valid only for an identical tint screen value in the circumferential path of the control strip patch.

These findings were confirmed with every other primary and secondary overprint color shown in Figure 6. Seen in this graph are the ΔE_{ab} values of the press run that was printed with the least ink feed decrease compared to that of the normal ink feed press run.

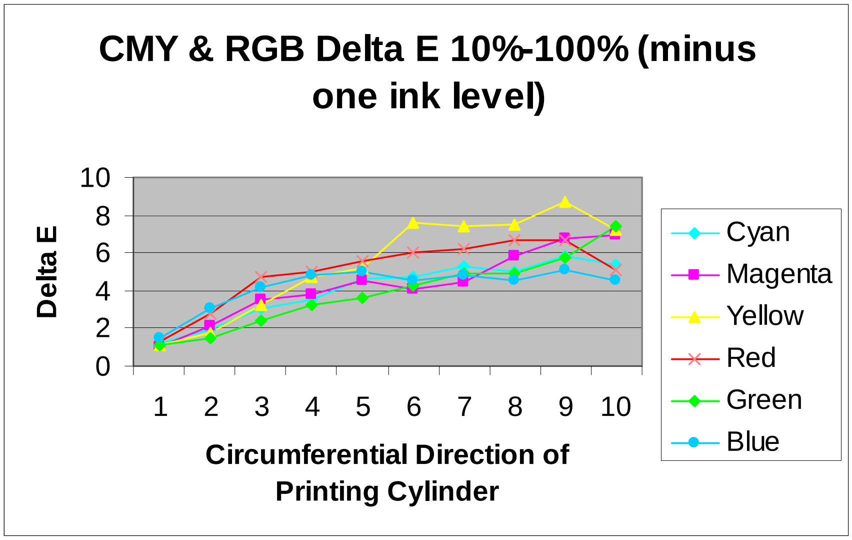


Figure 6.
CMY and RGB ΔE_{ab} values of ten tonal areas ranging from 10% to 100% printed at the same ink level.

It must be emphasized however that the different colorimetric effects in dark and light tonal areas brought about by identical changes in the amount of ink metered from the ink fountain is not in any way related to the inking system itself, but is a colorimetric phenomenon. In fact any printing process including digital printing processes are subject to this effect.

In conventional printing processes this problem could not be ameliorated without color correcting localized image areas in the pre-press stage, which really means a new set of printing plates would have to be produced. However, in digital printing processes there is a potential for adjustments during the printing phase, because digital presses, unlike conventional printing presses, do not have a fixed image carrier. Moreover, the imaging elements of digital printing presses have a direct electronic link with a digital image file, which allows changes, such as localized color corrections, to be made at the time of printing.

6. Conclusions

Unavoidable ink film thickness variations in the circumferential direction of offset lithographic presses do occur because of non-continuous ink feed of the inking system, as well as the press design, which requires an ink free zone, due to the plate cylinder gap. Combined, these conditions cause cyclical variations in the circumferential direction of image areas located in the circumferential direction of the plate cylinder.

The statistical ranges, as measured on the solid bands traversing the circumferential direction of the plate cylinder were, 0.13, 0.08, and 0.05 for cyan, magenta and yellow respectively. Consequently these variations must be accepted as the best achievable consistency.

Likewise, $\Delta E_{ab,}$ as measured in areas where the highest and the lowest ink film thicknesses were found are 2.0, 2.5, and 3.0 for cyan, magenta and yellow respectively. In terms of perceptibility, this means a very small to a medium deviation perceptible by even an inexperienced eye, (Heidelberg, 1995). Therefore, if ΔE_{ab} 3.0 for yellow is taken as a benchmark, tolerance limits narrower than +/- ΔE_{ab} 1.5, are beyond the technical capability of the press.

Ink film thickness adjustments have a markedly greater color difference effect on darker as opposed to lighter tonal areas. As ink film thickness continues to be decreased relative to an approved standard, darker tonal areas change at an accelerated rate.

Ink feed adjustments made on the basis of colorimetric measurements of control strip patches will be accurate only for tonal areas of identical tonal value as the control strip patch located in its circumferential path.

Differential colorimetric effects in dark and light tonal areas brought about by identical changes in the amount of ink metered from the ink fountain are not caused by the inking system itself, but are a colorimetric phenomenon that affects all printing processes.

Literature Cited

Dąbrowa T. and Gajadhur M., "Colour gamut of a press print and dependence of the basic attributes of overprint colours on the process ink film thickness", Surface Coatings International Part B: Transactions, 2006.

__________. "Colour gamut of a press print and dependence of the basic attributes of overprint colours on the process ink film thickness", Surface Coatings International Part B: Transactions, 2006.

Field, G.G., "Color and Its Reproduction" 2nd Edition, GATFPress, Sewickley, PA, 2006, p. 93.

GRACoL, "General requirements for Appliucations in Commercial Offset Lithography" 6th Edition, IDEAliance, Alexandria, 2002.

Heidelberg, Druckmaschinen AG, "Colour & Quality" Heidelberg, 1995, p. 81.

Kipphan, H., "Handbook of Print Media", Springer-Verlag, Berlin, pp. 215-216, 2001.

MacPhee, J., "Fundamentals of Lithographic Printing", GATF*Press***,** Sewickley, PA, 1998, p. 150.

__________. "Fundamentals of Lithographic Printing", GATF*Press***,** Sewickley, PA, 1998, p. 5.

__________. "Fundamentals of Lithographic Printing", GATF*Press***,** Sewickley, PA, 1998, p. 5.

__________. "Fundamentals of Lithographic Printing", GATF*Press***,** Sewickley, PA, 1998, p. 127.

Rech, H., "Untersuchungen des dynamischen Verhaltens ausgesuchter Konfigurationen eines Modellfarbwerkes", http://www.vdd-net.de/Publikationen/Rech/Farbwerkuntersuchungen.html, undated.

Acknowledgement

Much gratitude is owed to Jason Lisi, Assistant Professor at Ryerson University, for preparing the digital image files of the test form and to Peter Roehrig, Technician, also at Ryerson University, for conducting the experimental press run.