CMYK vs. KCMY Color Sequence Evaluation

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Abstract

Color sequence choice is one of the factors that affects the quality of printed color reproductions. The ideal sequence is largely dependent upon ink transparency and ink trap efficiency, both of which vary according to the printing system. Definitive research into the color sequence issue has been hampered by the experimental noise that occurs when running separate press trials of different sequences. A novel method, using a 5-color press, of studying the CMYK vs. KCMY color sequence choice for wet-on-wet offset lithography is presented. The first and fifth units of the press are used for black test images that print, respectively, with corresponding CMY test images located on the intermediate units. Noise-free pairs of CMYK and KCMY samples were thus obtained. The subsequent analysis revealed that the CMYK sequence produced both a higher Dmax and noticeably more neutral dark tones than the KCMY sequence. It is recommended that the experiment be repeated to confirm the quality superiority of the CMYK sequence, and then this sequence be unambiguously incorporated into the ISO 12647-2 standard, as well as into such related specifications as SWOP and GRACoL.

Introduction

Few experimental research studies have been published on the subject of optimal color sequence for four-color process printing. This lack might be due to the difficulty of conducting such studies, or to a perception that color sequence might be a relatively insignificant contributor to the overall quality of printed color reproductions.

If process color ink pigments were perfectly transparent, and if each succeeding printed ink film transferred perfectly to the one that preceded it, then color sequence would have no influence upon the appearance of the color reproduction. In practice, however, process color pigments are not perfectly transparent, and ink transfer efficiency (trapping) varies significantly according to whether or not the first-down ink, in a pair of inks under consideration, is dry or wet immediately prior to being overprinted by the second-down ink.

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Laboratory experiments using wet-on-dry ink transfer techniques can yield useful insights into the influence of color sequence selection, but for wet-on-wet printing, wet trap behavior also must be characterized. Past experimental work utilizing a 4-color press to evaluate the influence of color sequence choice has been hampered (or even discouraged) by the experimental requirement that "all other factors remain constant." It is extremely difficult to avoid experimental noise when making two or more trials of different color sequences on a 4-color press.

Literature Review

The ISO 12647 series of standards offer some limited guidelines for color sequence selection: for offset lithography, a CMY sequence is used to achieve the target secondary colors (ISO 12647-2, 2004), whereas for gravure a YMC sequence is used to achieve the target secondary colors (ISO 12647-4, 2005). Critical assumptions, which are absent from the ISO standards, are that the offset lithography CMY sequence is for wet-on- wet printing, and that the gravure YMC sequence is for wet-on-dry printing. The reversed orientation of yellow, magenta and cyan inks within the color sequence may be explained by considering the combined effect of ink transparency and ink transfer efficiency.

The lack of perfect transparency in the chromatic inks, and their influence upon the overprint reds, greens and blues, have been documented in an earlier study (Field, 1983). It was not until Bassemir and Zawacki (1994) developed a method for measuring ink transparency that it became possible to quantify this property. Their TAGA paper was illustrated with sample data demonstrating that yellow was the least transparent process ink and that cyan was the most transparent. Yellow had about one half the transparency (i.e., twice the opacity) of cyan.

Logic dictates that for maximum color gamut, the least transparent ink should be printed first in the sequence, and the most transparent ink printed last in the sequence. The Bassemir and Zawacki data therefore support the notion that YMC is the preferred sequence when printing wet-on-dry; indeed, this is the case for gravure color printing.

In the case of wet-on-wet offset lithography, Southworth (1979) reported a general use of CMYK and observed that printing yellow over magenta "will eliminate reds being too orange." An expanded conceptual understanding, informed by the ink transparency studies of Bassemir

and Zawacki, has been published (Field, 1999). In essence, undertrapping a more opaque (less transparent) ink over a less opaque (more transparent) ink results in a truer secondary (red, green, blue) overprint than if the ink sequence for that pair were to be reversed.

If ink transparency properties have settled the CMY sequence for wet- on-wet printing, the question of ideal sequence now shifts to the black (K) ink within the sequence. The first reported (Field, 1987) study of color sequence utilizing two separate runs on a 4-color press was hampered by the difficulty of keeping the non-sequence related printing factors constant for each press run. The same experimental noise difficulty was reported by Patel (2009) who tested the color gamut influence of several 4-color sequences for flexographic printing. In general, both studies supported the placement of black last in order to maximize color gamut.

A novel strategy designed to eliminate the experimental noise difficulty was suggested (Field, 2004) some years ago. This strategy requires the use of a 5-color press. The first and fifth units of the press are used to independently assess the position-dependent outcomes of a single ink relative to the inks printed on units the second, third, and fourth units. A single press run thus produces an evaluation of first versus last positioning of an ink within the sequence.

Given the CMY sequence agreement for wet-on-wet printing, a print quality factors experiment was conceived in order to evaluate the ideal position of just black within the sequence. Black could be interspersed within the chromatic colors, but a CMYK vs. KCMY pairing was thought to represent the most extreme in terms of print quality influence.

Experimental Procedure

In general terms, the first five units of a Komori 6-color press were used to produce the test images. The five inks consisted of a common 4-color process ink set with a KCMY descending tack order plus an extra black with nominally lower tack. The primary substrate was an 80# cover stock that was supplemented with other 80# substrates having various degrees of surface smoothness and gloss. The appendix provides more details of the production conditions. The experimental procedure was:

1. A test image was designed with solid C, M, Y areas plus their 2- and 3- color overlaps. Solid black images which were designed to partially overlap the chromatic colorants and their overprints were constructed. A resolution target (LTF/GATF Star Target) was chosen for inclusion beside each black image.

2. A set of test plates, each containing a duplicate set of the C, M, Y areas and their overprints, were produced and mounted on units two, three and four of the press.

3. Two black plates were produced: one with a single black bar positioned to partially overprint one CMY image, and the second with a single black bar positioned to partially overprint the other CMY image. One black plate was mounted on Unit 1 of the press and the other was mounted on Unit 5.

4. The press was made ready according to the usual plant specifications. Particular attention was paid to the requirement that the high tack black ink was loaded into the ink duct of the first unit, and that the low tack black was placed on the fifth unit.

5. The press run was made, making sure that the first and fifth unit blacks were even across their length, and that they exactly matched each other in density. The resulting image incorporated side-by-side examples of CMYK and KCMY evaluation targets (see Figure 1).

6. Densitometric, and colorimetric evaluations were made of each image pair. A glossmeter was used to evaluate the 4-color solids, and a microscope was employed to evaluate the resolution targets.

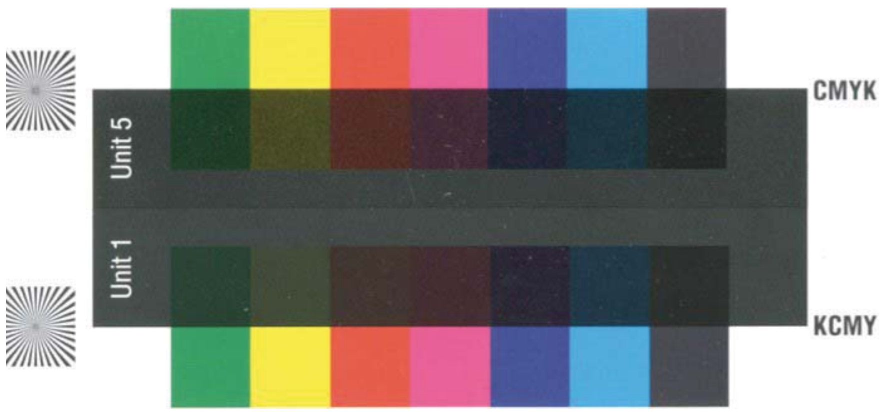

Figure 1: The printed color sequence test image. The two CMY images are each partially obscured by black. The black bar identified as Unit 5 prints over a portion of its CMY image, and the black bar identified as Unit 1 prints under its CMY image.

Results and Discussion

A single press sheet containing identical black density values for the Unit 1 and the Unit 5 images was a critical requirement for sequence

evaluation. This proved to be a simple requirement to satisfy. The density values measured from the primary substrate print are presented in Table 1.

Ink Color	CMYK Target	KCMY Target
Yellow	1.05	1.05
Magenta	1.49	1.48
Cyan	1.54	1.57
Black	1.62	1.63

Table 1: *Primary density values of CMYK and KCMY test sample.*

The maximum density of the 4-color solid (Dmax) establishes the tone reproduction and the image sharpness capabilities of a printing system. These values are presented in Table 2.

Printing Sequence	Density Values
CMYK	2.01
KCMY	1.87

Table 2: *The Dmax (maximum density capability) of the 4-color solids.*

Density values alone are sufficient for tone reproduction and sharpness capability assessments of color sequence effects, but colorimetric measurements are superior for assessments of 4-color solid neutrality. Table 3 presents the CIELAB colorimetric measurements.

Color Sequence	L*	a*	b*
CMYK	8.99	-0.17	-0.34
KCYM	11.68	-1.01	1.61

Table 3: *CIELAB values of the 4-color solids for the CMYK and KCMY color sequences.*

It should be noted that the greenish-yellow departure from neutral (which is: a*= 0.00, b*= 0.00) observed for the KCMY sequence can degrade image color quality. A scene comprised largely of reds and greens with a few small dark shadows may not be unduly distorted by the influence of a last-printing yellow. In the case of fashion advertising,

automobile brochures and night scenes, all containing considerable black areas, a yellow-last strategy can seriously degrade the printed image quality.

The gloss of the 4-color overprints will influence appearance (higher values produce higher visual contrast); therefore, these areas of the target were measured with a glossmeter in order to assess what effect, if any, color sequence had upon this property.

The tack differences between the first down high-tack black ink and the last down low-tack black might influence fine detail resolution, hence the inclusion of the resolution target in the test image. Assessment of the resolution images was made by measuring the angle between the printed target wedges. The larger the angle, the higher the resolution (see Figure 2).

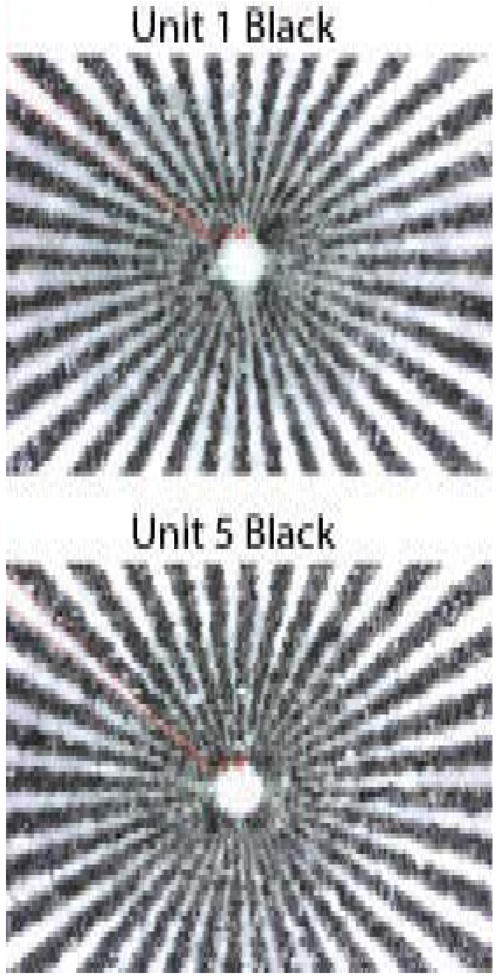

Figure 2: *GATF Star Target resolution images: top, high tack, first-down black; bottom, low tack, last-down black. The higher the angle between the wedges, the higher the resolution.*

Color Sequence	Gloss	Resolution
CMYK	52.6%	4.62 degrees
KCMY	40.3%	5.58 degrees

Table 4: *Gloss values for the CMYK and KCMY 4-color solids, and a measure of resolution (higher values are better) for the last-down and first-down black images.*

Analysis and Discussion

The CMYK sequence produced the higher Dmax by 0.14 density. This sequence also produced a 4-color solid closer to neutral than the KCMY sequence. Gloss was higher when black was printed last, but the lower tack of the last-down black ink was associated with lower fine line resolution. Some amplification of the results is in order:

The absolute gloss measurements are not accurate because the aperture size of the glossmeter's measuring port was larger than the 4-color solid being measured. The placement of the glossmeter on the sample, however, was carefully controlled so that the relative gloss differences would be valid.

The tack value of the last-down black was about equal to the tack of the yellow ink. If a set of CMY inks with higher tack values had been used, the transfer of black to the CMY combination would have been higher, thus increasing the Dmax.

It was noted that the tack of the magenta ink is about equal to that of the yellow.

Resolution can be influenced by impression pressure as well as ink tack, therefore, it is not known for certain that the lower resolution associated with the Unit 5 black image was due to its lower tack, incorrect impression pressure, or some other ink- or press-related factor.

The secondary test substrates that were run through the press (without any change in press settings) after the primary substrate run was completed, yielded results different in magnitude, but still exhibited the same relationships between the CMYK and KCMY sequences that have been recorded in Tables 1-4.

The gloss of both black inks appeared to be higher than the yellow ink. Blacks may be made this way in order to emphasize the visual contrast (and hence the legibility) of text matter. The 4-color overprint gloss values are influenced, to some degree, by this factor.

In response to a question posed on a LinkedIn forum about a rationale for running yellow last in the sequence, a blanket smash reason was offered. Apparently, web breaks do the most damage to the fourth unit blanket. If black is printed on that unit, the blanket has to be changed. If yellow is printed on the fourth unit, the press run often may be resumed without changing the damaged blanket. It is unlikely that the damage would be visible due to yellow's low visual contrast. This means, in essence, that quality (the superior visual properties of CMYK printing) is sometimes sacrificed for a gain in productivity (not having to change a smashed yellow blanket). The history of process color printing is replete with examples of similar quality-productivity tradeoffs.

Conclusions

1. Color sequence (CMYK vs. KCMY) does make a difference to the Dmax, shadow tone neutrality and gloss of printed color reproductions.

2. The CMYK sequence will produce superior (vs. KCMY) Dmax, dark tone neutrality and gloss.

3. The higher tack black ink used within the KCMY sequence may have been responsible for higher fine line resolution.

4. These conclusions do not seem to be influenced by changes in substrate.

Recommendations

1. The experiment should be repeated under a variety of conditions in order to verify the findings.

2. Offset lithographic printers should use a CMYK color sequence for maximum color gamut, better tone reproduction, color cast-free neutral tones, and sharper images.

3. Standards- and specifications-setting bodies should incorporate color sequence recommendations within their publications. In the case of wet- on-wet offset lithography, that sequence should be CMYK if the validity of the research presented in this paper has been confirmed by further experiments (Recommendation 1) and practical industry experience (Recommendation 2).

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Appendix

Production Conditions

Inks: Wikoff PC Hyperset Ink

Ink Tack (after 10 minutes): first-down black 20.0; cyan 19.0; magenta 17.4; yellow 17.5; last-down black 17.8

Substrate: 80# Creator Cover (matte side printed)

Plates: Kodak Sword

Fountain Solution: 3,000 Alkless, pH 4.01, conductivity 1780; etch 3451U

Offset Blankets (new for the run): Bottcher TT3021

Press: Komori 6-color sheetfed

Packing: zero height to bearer

Press speed: 10,000 IPH

Pressroom Environment: 72 degrees F; 45% relative humidity