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# Optimization of Ink Density for the Widest Color Gamut in a Lithographic Printing Process

**Tran Thi Thu, Luu Bach Hiep, Hoang Thi Kieu Nguyen***
*Hanoi University of science and technology, Hanoi, Vietnam
nguyen.hoangthikieu@hust.edu.vn

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**ABSTRACT**
In this study, the color gamut of a commercial offset printing system was investigated at different ink densities. The color gamut increases with increasing ink densities. However, there are optimal densities at which the maximum colorfulness of the primary inks and the overprint colors are obtained. The color targets and color gamut agree with ISO 12647-2:2013 standard.

Keywords : Color Gamut, Ink Density, Lithographic Printing, CIE Lab

## I. INTRODUCTION

Density is defined as the ability of a material to absorb light. The reflection density is calculated in densitometers (ANSI/ CGATS.4-1993) by

$$\text{Density}_R = \log_{10}(1/R)$$

Where R = Reflectance

Density values indicate to the press operator whether the amount of ink should be increased or decreased. This solid ink density directly affects dot gain, print contrast, and apparent trap [1, 2].

Color gamut is the entire range of colors and tones achievable by an imaging system. The color gamut of a printing device is determined by the hue, saturation, and lightness of its cyan, magenta, yellow, and black inks, the brightness, and other characteristics of the substrate on which they are printed [3]. Generally, the color gamut is specified in the hue–saturation plane, as a system can usually produce colors over a wide intensity range within its color gamut. The full-tone of process inks (cyan, magenta and yellow) and their two color overprints (red, green, and blue) mark the six endpoints of a device gamut, as shown in Fig. 1 [4].

The density impacts the color gamut directly. As the ink amount increases, the color of the ink becomes more vivid and colorful, i.e. the magnitude of the chroma is increased. Once it reaches its full tone, the hue slice becomes less saturated as it darkens. High density is expected to expand the color gamut. However, this case could also cause a shift of color hue and different print defects (drying and such) [4, 5]. In this matter, no rule is applied for every printing process with the ink-substrate-press combination.

The question arises here, how can we optimize the color gamut of a printing process? This study investigated the print density effect to get the widest color gamut for a commercial offset printer.

## II. EXPERIMENTAL

### A. Materials

The investigation was carried out in the CTP workflow. The test form (Fig. 1) was output using AM technology with a resolution of 175lpi. Heidelberg SM 74- printing machine, as shown in Fig. 2.

Offset printing Nippon speed (Cyan - C, Magenta - M, Yellow - Y) inks and Coated paper 100 g/m$^2$ were used. The printing process was carried out with the ink sequence Black - Cyan - Magenta - Yellow and a speed of 10.000 sph. The variation in the average and range solid ink density values (CMYK) of the printed sheets during the printing process was less than 0.1.

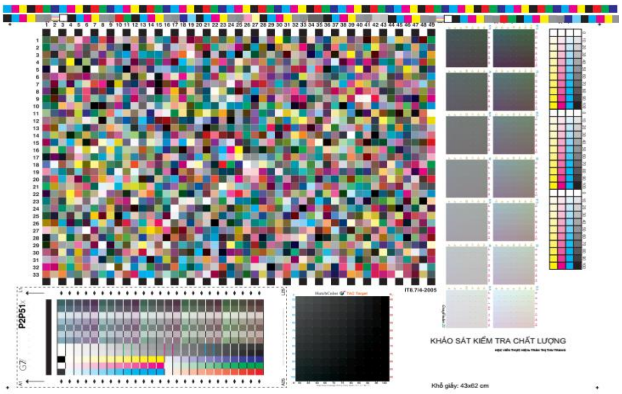


Figure 1: The CMYK test target

Figure 2: Offset printing machine SM74 - 2012

### B. Density and CIE Lab value measurement

The dry densities are measured by an X-Rite SpectroDensitometer 504, Inc.Grandville, MI

The color values were quantified numerically by the CIELAB color model. The CIE Lab values were calculated by an X_Rite SpectroDensitometer 504, Inc.Grandville, MI. The colour characteristics were calculated in the CIELAB color model by following equations [6].

Hue $H^* = artg(\frac{b^*}{a^*})$

Chroma $C^* = \sqrt{a^{*2} + b^{*2}}$

Color difference $\Delta E_{ab} = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$

### C. ISO12647-2:2013 standard

The ISO12647-2 standard data sets for PS1 paper [7] were recalculate by SCCA (Substrate Corrected Color Aim) Calculator based on the CIE L*a*b* values of the investigated substrate. The procedure utilizes the tristimulus correction methodology defined in ISO 13655 Annex A for correcting measurements based on two backing materials.

TABLE I

CIE L*a*b* values of ISO 12647-2 substrate corrected

| | GRACoL2013 CRPC6 IT8.7-4 | | | Substrate Corrected Results | | |
|---|---|---|---|---|---|---|
| | L* | a* | b* | L* | a* | b* |
| Substrate | 95.00 | 1.00 | -4.00 | 83.43 | -2.85 | 11.18 |
| Cyan | 56.00 | -37.00 | -50.00 | 48.72 | -34.67 | -31.37 |
| Magenta | 48.00 | 75.00 | -4.00 | 41.65 | 63.79 | 4.78 |
| Yellow | 89.00 | -4.00 | 93.00 | 78.08 | -7.05 | 88.43 |
| Black | 16.00 | 0.00 | 0.00 | 14.13 | -0.33 | 2.68 |
| Red | 47.00 | 68.00 | 48.00 | 40.76 | 57.65 | 44.78 |
| Green | 50.00 | -66.00 | 26.00 | 43.41 | -59.36 | 28.85 |
| Blue | 25.00 | 20.00 | -46.00 | 21.62 | 15.98 | -31.64 |
| CMY | 23.00 | 0.00 | 0.00 | 19.92 | -0.79 | 4.03 |
| CMYK | 9.05 | 0.20 | 0.39 | 8.74 | 0.41 | 1.34 |
| CMY HR | 57.46 | 0.38 | -2.03 | 50.01 | -2.02 | 7.68 |
| K HR | 60.40 | 0.46 | -2.59 | 52.62 | -2.07 | 7.64 |

## III. RESULTS AND DISCUSSION

### A. Effect of ink density values on color gamut

In this series of experiments, 6 samples were printed with the ink densities (CMYK) decreasing in the range of typical ink densities, Dc = 1.45, Dm = 1.40, Dy = 1.0, Dk = 1.7 with ΔD = 0.1. The experimental data are given in Table 2. The changing color values L*a*b* at different densities are reported for solid colors CMYKRGB (Table 1). The color characteristics of Lightness, Hue and Chroma, are presented in Table 3. The relationship between lightness and chroma for a particular hue is built by L*C* plots of cyan, magenta and yellow primaries (Fig. 3). Note that the hue slice begins at the top left, and that's where the paper white is located and goes to the darkest black (lower left corner).

TABLE II

CIE L*a*b* values of solid colors at different ink densities

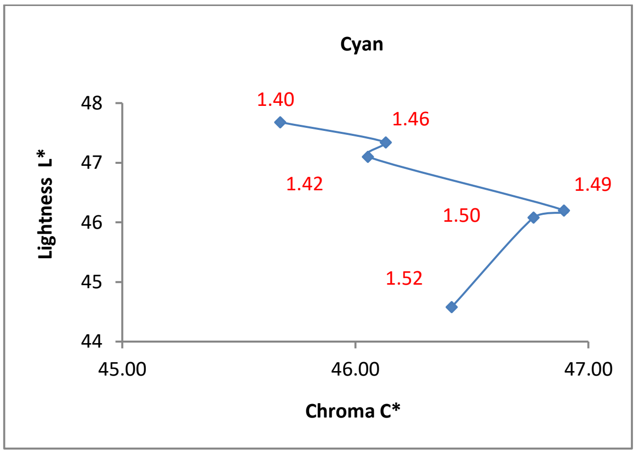
| Sample | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| | Dc | 1.40 | 1.42 | 1.46 | 1.49 | 1.50 | 1.52 |
| | Dm | 1.32 | 1.35 | 1.38 | 1.40 | 1.46 | 1.49 |
| | Dy | 1.01 | 1.04 | 1.09 | 1.10 | 1.13 | 1.18 |
| C | L* | 47.68 | 47.34 | 47.30 | 46.20 | 46.08 | 44.58 |
| | a* | -36.29 | -36.26 | -35.59 | -36.07 | -36.09 | -35.75 |
| | b* | -27.74 | -28.87 | -29.23 | -29.97 | -29.74 | -29.60 |
| M | L* | 43.13 | 42.55 | 42.28 | 41.32 | 40.88 | 40.12 |
| | a* | 59.95 | 61.11 | 59.71 | 61.46 | 62.82 | 60.65 |
| | b* | -2.82 | -0.35 | -0.09 | -0.08 | -0.62 | 0.40 |
| Y | L* | 79.20 | 78.56 | 78.13 | 78.25 | 77.71 | 75.94 |
| | a* | -6.51 | -6.12 | -6.23 | -5.83 | -7.31 | -7.40 |
| | b* | 73.05 | 74.39 | 75.33 | 76.21 | 80.23 | 77.56 |
| K | L* | 17.06 | 14.68 | 14.36 | 13.96 | 13.92 | 13.81 |
| | a* | -0.40 | -0.35 | 0.59 | 1.28 | 2.39 | 0.07 |
| | b* | 9.79 | 9.71 | 7.47 | 5.89 | 1.41 | 8.08 |
| R | L* | 39.04 | 40.71 | 41.43 | 42.33 | 42.83 | 43.77 |
| | a* | 50.70 | 52.57 | 51.62 | 50.07 | 51.28 | 50.23 |
| | b* | 36.47 | 37.17 | 35.58 | 35.17 | 34.59 | 32.65 |
| G | L* | 41.42 | 43.81 | 44.23 | 45.21 | 45.50 | 46.20 |
| | a* | -50.88 | -51.45 | -52.21 | -51.26 | -52.35 | -52.18 |
| | b* | 30.77 | 32.21 | 29.85 | 29.68 | 29.30 | 29.04 |
| B | L* | 39.04 | 40.71 | 41.43 | 42.33 | 42.83 | 43.77 |
| | a* | 50.70 | 52.57 | 51.62 | 50.07 | 51.28 | 50.23 |
| | b* | 36.47 | 37.17 | 35.58 | 35.17 | 34.59 | 32.65 |

TABLE III

Characteristics of solid colors at different ink densities

| Sample | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| C | L* | 47.68 | 47.34 | 47.30 | 46.20 | 46.08 | 44.58 |
| | H* | 217.39 | 218.58 | 219.40 | 219.72 | 219.49 | 219.62 |
| | C* | 45.68 | 46.13 | 46.05 | 46.90 | 46.76 | 46.41 |
| M | L* | 43.13 | 42.55 | 42.28 | 41.32 | 40.88 | 40.12 |
| | H* | 357.3 | 359.7 | 359.9 | 359.9 | 359.4 | 360.4 |
| | C* | 60.02 | 61.11 | 61.23 | 61.46 | 62.82 | 60.65 |
| Y | L* | 79.20 | 78.56 | 78.13 | 78.25 | 77.71 | 75.94 |
| | H* | 95.09 | 94.70 | 94.73 | 94.37 | 94.39 | 95.45 |
| | C* | 73.34 | 74.64 | 75.59 | 76.43 | 82.47 | 77.91 |

As observed in Fig.3, for all the inks, the magnitude of the C* moves to the right when the ink amount increases. However, it reaches its full tone at sample 5, and the hue slice becomes less saturated as it darkens (sample 6). Therefore, the color gamut seems to get the widest size in this sample 5 (Fig. 4). The corresponding ink densities are Dc = 1.50, Dm = 1.46, and Dy = 1.13. At this sample, Black ink also get a good neutral color, Dk = 1.75, a* = 2.39, b* = 1.41



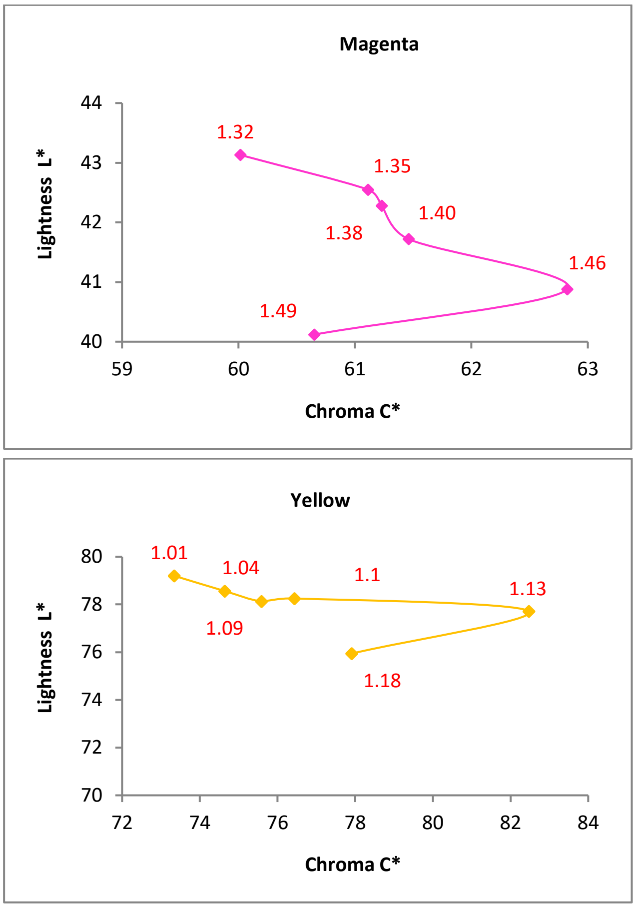



Figure 3: L*C* gamut plots of cyan, magenta and yellow hue

The CIE L*a*b* of solid colors and overprints of the printed image (sample 5) are compared to ISO 12647-2 standard (Table 4). The color difference $\Delta E_{ab} < 5$ for all the solid colors. This result indicates that the printing process adapted to the international standard. Fig. 5 illustrates that the ISO 12647-2 gamut is slightly larger than the obtained gamut at two-color overprints (R, G, B). However, as mentioned in ISO 12647-2, the secondary colours red, green and blue depend on conditions that include the printing sequence, the rheological and transparency properties of the inks, mechanics of the press and the surface characteristics of the print substrate. Thus, it is not possible to state tolerance windows for both solids and overprints [7]

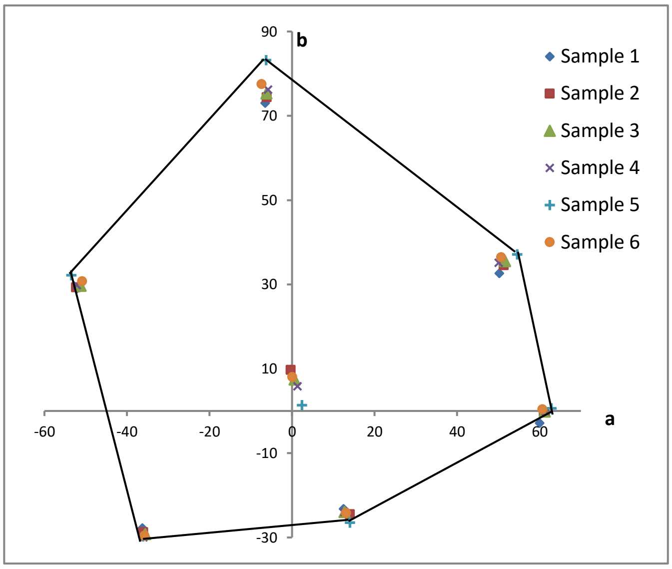



Figure 4: Color gamut at different ink densities

TABLE IV

CIE L*a*b* of printed image compared to the standard

| Color | L | a | b | $\Delta E_{ab}$ | ISO $\Delta E_{ab}$ |
|---|---|---|---|---|---|
| C | 46.08 | -36.09 | -29.74 | 3.13 | 5 |
| M | 40.88 | 62.82 | 0.62 | 4.34 | 5 |
| Y | 77.71 | -6.31 | 83.23 | 4.49 | 5 |
| K | 13.92 | 2.39 | 1.41 | 2.92 | 5 |

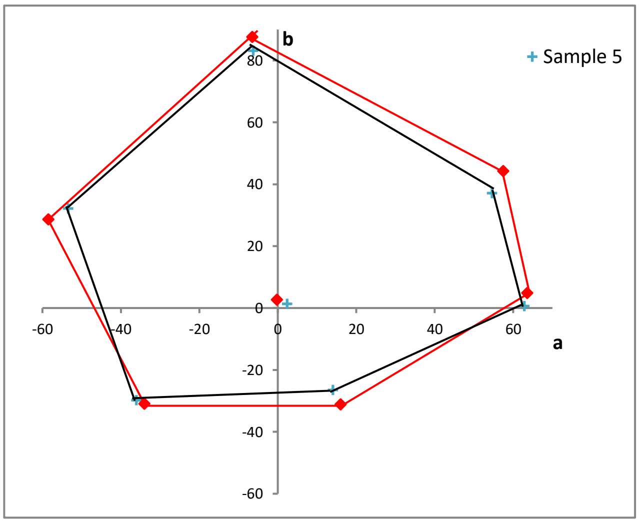



Figure 4: Obtained color gamut compared to the standard

All the results optimize ink densities that induce a color gamut that exhibits maximum colorfulness of the primary inks, the overprint colors and a very dark neutral shadow. The optimum densities also allow archiving color targets and color gamut accepted by ISO 12647-2 for the investigated substrate.

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## IV. CONCLUSION

The printing system was optimized in ink densities to get the widest color gamut. The color values of solid colors and overprints are suitable with ISO 12647-2:2013 for the investigated paper. The results contribute to controlling and improving printing quality and cost savings.

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