Color Characterization of Various Ink, Substrate and Printing Process Combinations

Walter F. Zawacki* and Lawrence C. Steele**

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Abstract: The gamut of colors that can be reproduced depends on the combination of ink, substrate and printing process as well as print characteristics, such as, ink density, dot gain and trapping. ANSI CGATS TR 001-1995 provided public access to color characterization data for offset printing meeting the requirements of ANSI/CGATS.6-1995 (SWOP proofing). Work on defining the color gamuts for additional substrates and printing processes is currently in process. Protocols have been developed for the press printing and colorimetric measurement of the IT8.7/3 target. A comparison of the color gamuts clearly shows the importance of using the correct characterization data to prevent out-of-gamut experiences. Use of these data as the primary colorimetric reference by all manufacturers of color separation, management and proofing systems will help improve the consistency between data prepared in, or exchanged between, systems manufactured by different vendors. It should also help to improve the communication chain among all those involved in the reproduction process. This paper provides insight into the color gamut of various reference printing conditions being developed by CGATS and ISO TC 130 with support from industry associations such as SNAP, SWOP and GAA.

Introduction

Have you ever gotten a job on press and then found out that an acceptable match to the proof could not be achieved? Or worse yet, have you gotten a call from the customer rejecting the job that you printed last week because the color was not right? While there are a number of possible reasons for these situations, one of the possibilities is that you encountered an out-of-gamut experience.

* Flint Ink and Chair of ANSI CGATS SC4 Process Control

** Kodak Polychrome Graphics and Chair of ANSI CGATS SC3 Metrology

The gamut of colors that can be reproduced depends on the substrate being printed, the colorants used in the inks and the printing process being used. The problem probably would have been prevented if the separations were made with the correct color characterization data. Until the publication of SWOP proofing data in ANSI CGATS TR 001-1995, an industry accepted color characterization was not available for any of the printing processes. As a result, each manufacturer of front-end software has had their own color characterization data and it might be different than everyone else's. Therefore, when separations from different sources are combined on the same form, there may be problems achieving acceptable color on all the pages because the separations were made for different combinations of paper, ink and printing process conditions. To help improve the communications chain among all those involved in the reproduction process, color characterizations for various reference printing conditions are being developed by CGATS and ISO TC 130 with support from industry associations.

We will discuss the testing and measurement protocols that have been developed, the color gamut information that has been obtained, the status of the standards activities related to color characterization and the direction of the future work.

Experimental

Press tests have been arranged with the help and cooperation of industry groups such as SNAP, SWOP and GAA to obtain the test samples needed to determine the color characterization data. It is important that the color characterization data be obtained using a standard test target and that the data represent the center point of the existing specifications. For this reason, the target selected was the extended version of the IT8.7/3 target, which is also International Standard ISO 12642:1996. Also, to obtain data that represent an "average" of the printed results at the specified conditions, it is desirable to print test samples at several locations.

SNAP Characterization. This paper will describe the recent activities within the newspaper and insert industry segment as an example of the proposed process for developing color characterization data.

To insure consistency of the input materials for the SNAP testing, films with 65, 85 and 100 lines/inch screen rulings as well as images that were right-reading and wrong-reading with the emulsion down (RRED and WRED respectively) were produced at one location on the same imagesetter. All of the films were checked to make sure that none of the dot percentages on the films varied by more than 2% from the electronic file input values. Films with different screen rulings and orientation were needed because the SNAP document is being revised and will now include specifications for offset, letterpress and flexographic printing.

To insure consistency in the way the press testing was conducted, a testing protocol that included the following information was developed.

1. Plates made with the original supplied films.
2. Process color inks that conform to the ink specifications. C-M-Y color sequence for offset and letterpress and Y-M-C for flexo.
3. Wash up the press rollers to remove ink that may have become contaminated from back-trapping and to remove any ink buildup. Run spectral curves on the printed samples of each process color and check for a dip in the spectral curve at the maximum absorption point of the earlier down process colors that would indicate contamination. The yellow and magenta curves should also be checked to see that the high reflectance portions go up to the level of the unprinted paper (within 1% reflectance).
4. Test images to be printed on an inside page with no printing on the reverse side or the facing page. This is to prevent marking in the folder and to eliminate show-through that could affect the measurements.
5. Solid ink densities controlled to the specified values using suitable color control bar patches.
6. Midtone tone value increase / dot gain controlled within the specified values using the control bar patches.
7. Collect at least 100 consecutive printed samples that meet the specified values and indicate whether all the samples were printed on paper from the same roll.
8. Provide a specified list of press test information.

The color control bar on all of the printed samples was measured using a scanning densitometer. The profile of the run was examined for conformance to the specified density and tone value increase / dot gain values and for consistency of the run. The 25 consecutive samples that best met these criteria were selected for the colorimetric measurement process.

A measurement protocol was developed to insure consistency in the measurement process. All of the measurements are made in conformance with ISO 13655:1996 (ANSI CGATS.5 is equivalent US standard).

1. A densitometry-based profile of the 25 printed samples was obtained using selected patches on the IT8.7/3 target. A weighted ranking for each sheet is computed by summing the density differences for the four solids plus twice the density difference for each of the 50% patches. The 50% patches are given a greater weight because the midtones contribute more to the visually apparent variation in color than do the solids. This weighted ranking is used to select the sheets closest to the average for further measurement.

2. Nine (9) sheets are selected as close to the average of the sample set as possible, using the weighted analysis described above for complete measurement of the IT8.7/3 target.
3. All 928 patches of the IT8.7/3 target (Basic & Extended) are measured using a spectrophotometer on three (3) samples by the coordinating organization lab. Colorimetric data are also computed.
4. One (1) of the measured samples and two of the unmeasured samples are sent to each of two (2) additional labs for similar measurement. Measurement conditions and instructions are specified. Each lab is required to complete an inter-instrument agreement test, using the previously measured sheet and associated colorimetric data, and conform to specified limits before further measurements are made.
5. All of the data is evaluated for consistency and data errors by the coordinating organization.

Once the coordinating organization has received all the data, the sets of CIELAB data for each patch are then grouped and the average and standard deviation for L*, a* and b* computed for each patch. Based on work by Dolezalek (1994), the Delta E^*_{ab} distribution is assumed to be represented by the three-dimensional chi-squared function. This approach uses the average of the standard deviations of L*, a* and b* as a single parameter (s-avg) to characterize the probability distribution. Any patch that has a value for s-avg greater than 1 is examined to determine if potential errors exists or if the variation can be explained by noise in the samples or measurement process. Data that is obviously in error is identified at this point to allow it to be excluded during the final stage of data summation. In addition a record is kept of the patch and measurement site of the excluded data to allow additional error analysis if the number of data points excluded become excessive or shows any pattern.

The final data summation step goes back to the spectral data. Any data identified earlier as suspect is excluded and the remaining spectral data for each patch is averaged to provide the average spectral data for each patch. Using this data, the associated CIEXYZ and CIELAB values are computed using the weighting functions of CGATS.5. This becomes the final characterization data that is reported. An ANSI CGATS Technical Report containing all of the test information and the colorimetric data is prepared and circulated for full ANSI CGATS committee approval. This is the process that has been followed in the United States; similar testing is being conducted in Europe and Japan.

Results

Using the color characterization data, we can plot the color gamut. Figures 1 and 2 were plotted using the data in ANSI CGATS TR001. Figure 1 is a CIELAB a* vs. b* plot which shows the color gamut for SWOP proofing. The six corner points of the polygon are the location of the primary (cyan, magenta and yellow) and secondary (red, green and blue) solid ink colors. The points forming the spines are the location of the tone values with increasing tone value from the center out. The center point is the substrate, which in the case of SWOP proofing is 60# Champion Textweb, a #5 groundwood stock.

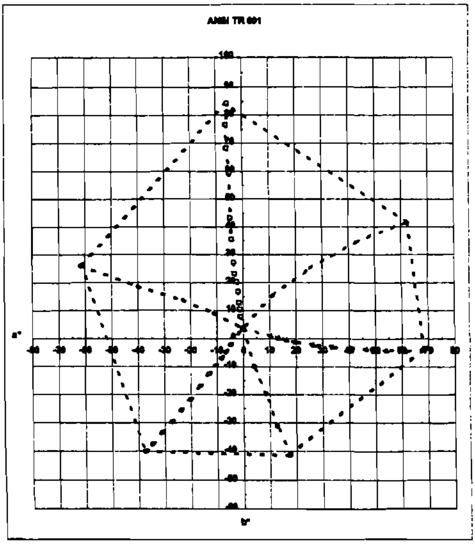

Figure 1. CIELAB a* vs. b* plot showing SWOP proofing color gamut.

Figure 2 is a CIELAB L* vs. C* plot which shows the relationship between lightness and chroma for SWOP proofing. The upper line shows the increase in chroma and decrease in lightness with increasing tone value. The lower line shows the decrease in chroma and lightness with increasing black tone value. This plot helps to illustrate changes in lightness and chroma which are not seen in the a* vs. b* plot.

Figures 3 and 4 show the comparison in color gamut and lightness vs. chroma between gravure printing by a Japanese printer on a heavy-weight coated stock and SWOP proofing on a #5 groundwood stock. The color of the heavy-weight coated stock and the higher densities obtained on it with the gravure printing process result in a larger overall color gamut. Note that the gravure magenta ink becomes yellower in shade at the higher tone values which results in a smaller gamut of colors in this area of color space.

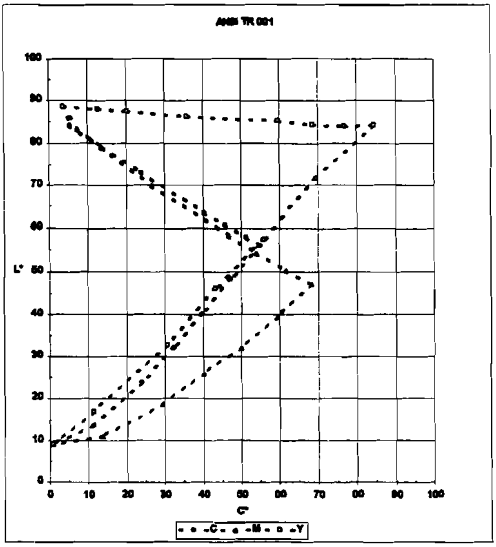

Figure 2. CIELAB L* vs. C* plot showing the relationship between lightness and chroma for SWOP proofing.

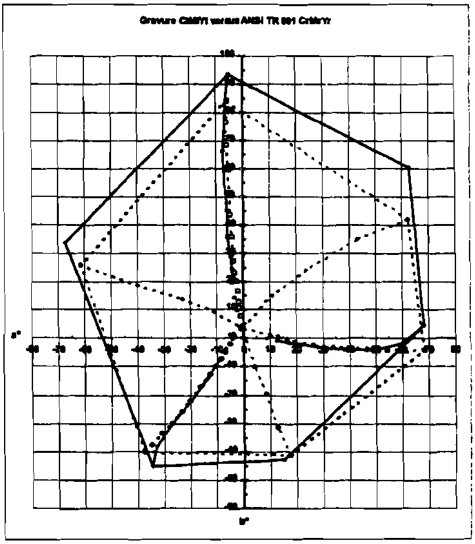

Figure 3. CIELAB a* vs. b* plot comparing gravure printing on a heavy-weight coated stock (—) to SWOP proofing on #5 groundwood stock (- - -).

Figure 4 shows the higher chroma obtained with the gravure cyan and yellow inks on the heavy-weight coated stock. This plot shows that the maximum chroma of the magentas are approximately equal but it does not show the shade difference seen in the a* vs. b* plot. Data for the primary colors with increasing tones of black were not available for the gravure samples so the bottom line could not be plotted.

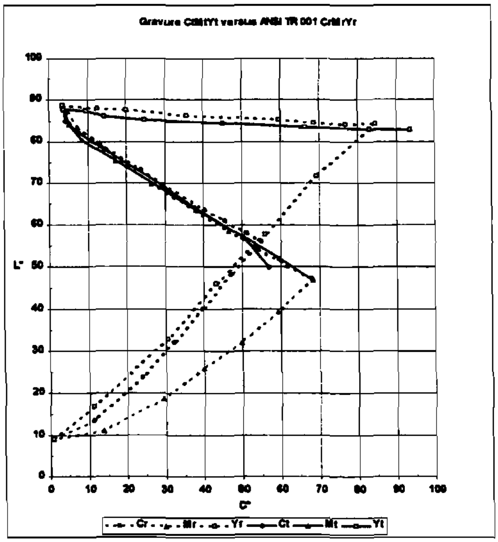

Figure 4. CIELAB L* vs. C* plot comparing gravure printing on a heavy-weight coated stock (—) to SWOP proofing on #5 groundwood stock (- - -).

Figures 5 and 6 show the color gamut and lightness vs. chroma plots for SNAP coldset offset printing on newsprint. Additional data is still being obtained so this color characterization is not finalized. However, the data shows that the color gamut obtainable on newsprint is significantly smaller than that obtained on #5 groundwood. The colorants used in both sets of inks are the same and both sets of inks match when printed on newsprint at SNAP densities and also on #5 groundwood at SWOP densities. The difference in the color and light scattering properties of the stocks are the main factors in the color gamut differences.

Figure 6 shows the lower chroma obtained with coldset offset printing on newsprint. The lightness ranges from an L* of 30 to 82 for SNAP printing on newsprint while the L* ranges from 10 to 88 for SWOP proofing on #5 groundwood. The rougher newsprint scatters the light more so the solid ink prints do not appear as dark as they would on the coated groundwood stock and the chroma of the printed solids is lower on newsprint.

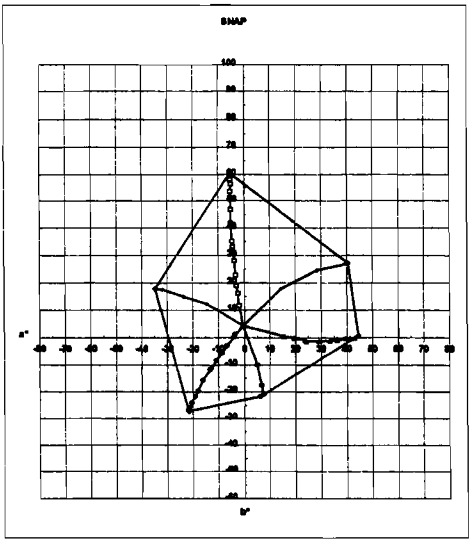

Figure 5. CIELAB a* vs. b* plot showing SNAP offset color gamut.

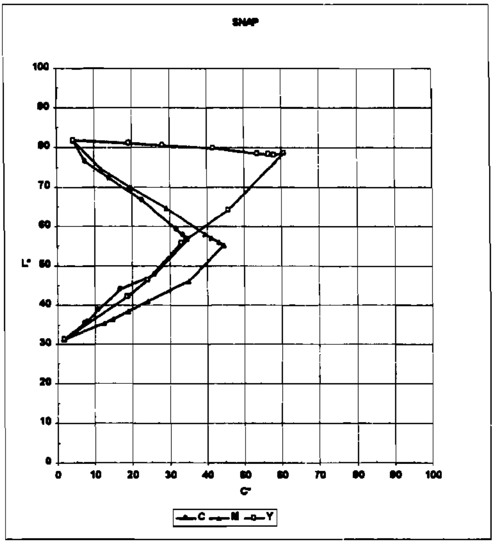

Figure 6. CIELAB L* vs. C* plot for SNAP offset printing.

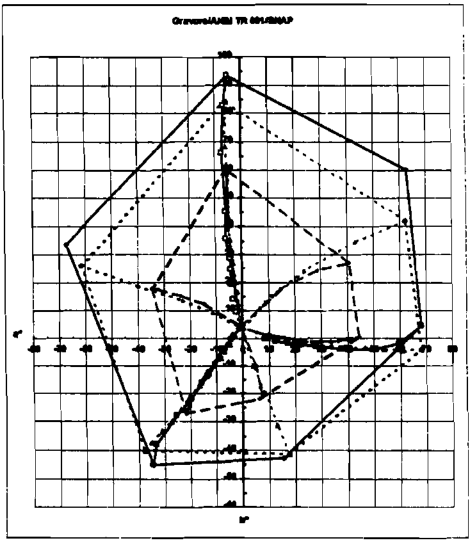

Figure 7. CIELAB a* vs. b* plot comparing gravure printing on a heavy-weight coated stock (—), SWOP proofing on #5 groundwood paper (- - -) and SNAP offset printing on newsprint (– – –).

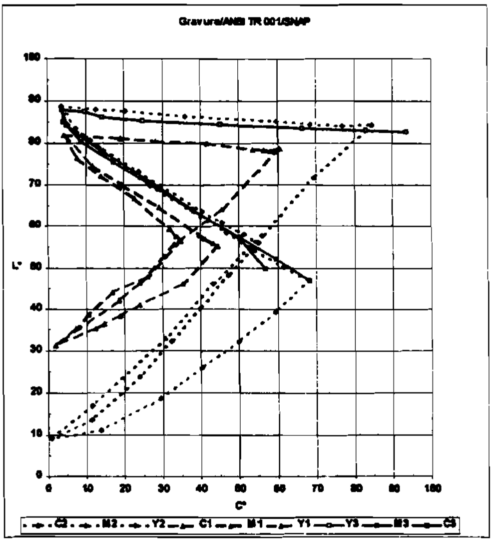

Figure 8. CIELAB L* vs. C* plot comparing gravure printing (—), SWOP proofing (- - -) and SNAP offset printing on newsprint (– – –).

Figures 7 and 8 compare the color gamuts of the three paper, ink and printing process combinations. The differences in the color gamuts illustrate why you would have out-of-gamut experiences if the color separations were made using color characterization data for SWOP proofing and printed on newsprint to SNAP specifications.

Discussion

The U.S. activity to develop color characterization data has been proceeding based on printing process and substrate combinations using normal inks. Most of the work has developed around existing industry specifications – SWOP offset proofing, SNAP coldset offset printing and SWOP publication gravure printing. The addition of letterpress and flexo specifications as part of the SNAP revision provided an opportunity to collect color characterization data as part of the testing process. The GAA (Gravure Association of America) Color Correlation Task Force has been conducting testing on a variety of substrates.

As mentioned earlier, ANSI CGATS TR 001-1995 contains the color characterization that represents SWOP offset proofing. Proofing vendors already make use of TR 001 for SWOP Application Data Sheets for set up, calibration and verification. The SNAP coldset press testing for offset, letterpress and flexo printing has been completed and the samples are in the measurement process. Publication gravure tests have been run by GAA and the samples are being evaluated. The Flexographic Technical Association (FTA) FIRST (Flexographic Image Reproduction Specification & Tolerances) committee plans flexo-packaging tests. The GRACoL (General Requirements for Application in Commercial offset Lithography) committee is conducting tests on various coated and uncoated stocks used in commercial printing. This testing will provide ink and paper color for various proofing and printing applications. It provides a definition of input materials' characteristics and reference print condition data that includes CIELAB colorimetric data, density and tone value increase. Proofing vendors will have new, definitive aims, as additional technical reports become available.

ISO TC 130 has been defining the color and transparency of ink sets for four-color printing in a series of standards with the ISO 2846 designation.

Graphic technology – Colour and transparency of ink sets for four-colour printing —
Part 1: Sheet-fed and heat-set web offset lithographic printing
Part 2: Coldset offset lithographic printing
Part 3: Gravure printing (in process)
Part 4: Screen printing (in process)
Part 5: Flexographic printing (just starting)

These standards provide the test methods for proofing the inks on reference substrates and the reflection colorimetric and transparency values for compliance. Color characterization data developed with inks conforming to these standards and printed to the specifications of the ISO 12647 series should receive international acceptance.

Future Work

The vision for the future is the establishment of reference printing characterization data sets that include color gamut and tone reproduction information that specify the relationship of CMYK to CIELAB. These data sets can be used for proofing/printing system verification. In fact, there are already printers that are using the ANSI CGATS TR 001 colorimetric data to correlate their proofing system and production press. CGATS SC6, Digital Advertising Exchange is currently working on a proposed reference CMYK input profile based on the ANSI CGATS TR 001 data set.

Reference characterization data sets can and should be the aim establishing the relationship between image data and color intent for all prepress activities including proofing, both on-site and remote, as well as for production printing. Color management can be enabled using color profiles of calibrated and controlled output devices in conjunction with profiles representing reference printing conditions to maintain color throughout the many steps from capturing an image to printing the image. The same approach and color management tools can provide simplification and reduced costs even in vertically integrated operations requiring private reference conditions.

Reference Printing Conditions. As the color characterization work has progressed, it was discovered that similar color gamuts were obtained on a particular stock even with different printing processes if the shade of the inks were similar and they were printed to the same solid ink densities. Some "internal" differences may result from differences in tone value increase and/or trapping characteristics. Since these differences can be compensated for using color management with ICC profiles, it appears that the establishment of six reference printing conditions based on stock type will cover the majority of situations. Some possible classifications for reference print conditions are:

1. Premium coated (heavy-weight coated)
2. Coated
3. Publication grade (#5 groundwood - SWOP)
4. Supercalendared
5. Uncoated
6. Newsprint (SNAP)

Once the necessary data is collected, Technical Reports containing data for the color of the stock and the inks along with the printing characteristics would be prepared. Color profiles would be created from known CMYK input / CIELAB output and contain gamut and tone compression, color separation methods, black to color relationship (UCR/GCR/TVS) and, sometimes, intellectual properties. For data exchange, color management can become an integrated part of the overall graphic arts process that is automatic.

Conclusions

1. The difference in the color and light scattering properties of the stocks are one of the main factors in the color gamut differences.
2. Similar color gamuts were obtained on a particular stock even with different printing processes if the shade of the inks were similar and they were printed to the same solid ink densities.
3. The process used in developing the SNAP color characterization data has resulted in proposed protocols for press testing and sample measurement. It is recommended that these protocols or similar methods be used when developing color characterization data for additional applications.
4. Six reference print conditions could cover the bulk of color data definition and proofing requirements within commercial, publication and newspaper applications.
5. Color characterization data for various reference printing conditions enables better and easier prepress through identification of the meaning of color data, controlled proofing and potential new capabilities and freedom for printers.

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