

Color gamut – a new tool for the pressroom?

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ABSTRACT: Customers want the best ink set on the brightest, whitest, or best looking substrate that can be used on the fastest press or printer. Nevertheless, sometimes using the highest quality, more expensive substrate won't give the greatest overall results. Based on information from manufacturers, we can predict which substrate or ink set will give us better or worse results. In this study, we tested different substrates to determine how the substrate properties affect the overall final presentation of the prints. Our results show that there is no correlation between the optical properties of the substrate (e.g., brightness, whiteness, and opacity) and the specific range of colors that can be produced on such substrates. In the case of ink-jet substrates, smoother and less permeable substrates can reach the highest values of colors printed. Gravure samples showed no evident correlation between any of the properties, optical or physical, and color gamut volume.

Application: Color gamut provides an additional way to characterize the printability of a substrate that is not accounted for by other measurements.

What do we need to know about substrate? For any print job, we usually pick what we think are the best substrate qualities for our purpose: paper grade (free coated sheet, LWC, board, uncoated, coated, 100% cotton, pH, buffered, lignin free, etc.), physical properties (roughness, porosity, permeability, etc.), and optical properties (brightness, whiteness, opacity, gloss, etc.).

Previous work in this area has expanded our knowledge, but we still lack a clear understanding of the problem. Work by Preucil in 1962 showed that color shift of the primary colors is caused by the ink surface light scattering phenomenon [1]. He also suggested combining two substrate surface properties into a single paper surface efficiency factor as a predictive factor of the level of color reproduction. Later, Zawacki and Steel determined that the difference in color and light scattering properties of the substrate is a major factor in color gamut differences [2]. Yang and Kruse, in their work on chromatic variations and color gamut reduction resulting from ink penetration, found that ink penetration can cause remarkable color differences, or hue shifts, and significant reduction of color saturation and color gamut volume [3]. A study by Nörberg and Andersson showed the importance of including the influence of the paper in the color management workflow. They noted that the amounts of brightening agents in the paper or top layer of the substrate significantly affect the color reproduction. They also pointed out the importance of the ink and paper interaction in color reproduction [4]. Work by Klamann has described paper's influence on International Color Consortium (ICC) profiles [5,6]. Crucial properties that influence the color rendering and reproduction for the offset printed substrates include the shade, structure, and absorption of the substrate.

Today's markets are driven by customer demands. In the case of substrates, the brighter or whiter paper will give cus-

tomers the appearance they desire, but it also will cost more. To produce greater brightness and whiteness, papermakers stack optical brightening agents (OBAs) or fluorescent whitening agents (FWAs) into the paper base and coating. The major uses of these chemical substances are to hide the yellowish tint of paper, textiles, coatings, and plastics by giving them a bluish tint. [7]. Typically, these materials have excitation maxima in the very near ultraviolet (UV) range (340-400 nm) and emit in the 430-460 nm range [8].

OBA manufacturers promote their products by saying that with whiter paper customers will get better or more color; but do we really need that special, more expensive, white background? Is it really going to give the best results? In the end, how much of the substrate do we see? Aren't we trying to cover it with a layer of special colored chemicals called inks? The real questions are: What do customers really want? What do we need to know about substrate? It has been proposed that the right combination of different properties (e.g. brightness and opacity) can offer high print quality [9].

All human-visible colors can be represented as points in a three-dimensional (3-D) coordinate system (e.g., the CIE Lab Color Model) [10]. Knowledge of the color gamut surface is useful for color science-related tasks, such as visualization, gamut volume calculation, and deciding how many colors outside the color gamut can or cannot be reproduced. Two different methods can be used to reconstruct the color gamut surface. One, the colorant space method, is based on an assumption that the maximum or minimum color coordinate points lie on the surface of the gamut. The other, the geometric method, is based only on a set of point coordinates in a device-independent color space. Both methods require a large number of color space points to precisely describe the color gamut surface and volume [11-17].

A color gamut is a delimited region in color space; it con-

tains colors that are physically achievable by a given device or that are present in a given image. The set of all colors that can be produced by a printing system is that system's color gamut. If all of the colors in a color gamut were plotted in a 3-D coordinate system they would form a color solid. The volume of the solid would be proportional to the effective number of colors in the gamut. Color gamut mapping is an integral part of color management system [18,19] and has become a very important research tool for the quantitative comparison of the effects of colorants, media, and other variables that affect printing behavior. Color gamut often is displayed as a full 3-D volume, because critical data are generally lost in the two-dimensional (2-D) representation, which may lead to incorrect interpretations of the results [20]. Many software packages are commercially available that use the gamut's full profile data to display 2-D and 3-D chromaticity plots and relevant statistics.

The gamuts are always generated from measuring a large set of printed color patches that were created to define the device's profile. An example of the chart is the ECI 2002 CMYK chart (**Fig. 1**). The ECI 2002 CMYK chart is a superset of the current ISO 12642 graphic technology target. All 928 patches of the current ISO 12642 (also known as ANSIIT8.7/3) chart are contained in the 1485 patches of the new ECI 2002 CMYK chart [21].

EXPERIMENTAL

We closely investigated different samples of substrates. The first set of substrates represented high-end fine art ink-jet-coated papers. All the ink-jet samples had matte finishes and were recommended to be used for ink-jet pigmented ink sets, such as Epson's UltraChrome, Canon LUCIA, or HP Vivera pigment-based inks. Printers usually use seven or more different color channels: cyan (C), light cyan (c), magenta (M), light magenta (m), yellow (Y), black (K), light black (k), light-light black (lk), red (R), green (G), and blue (B). The studied set was composed of CcMmYKk ink set. Half of the samples contained a certain amount of the optical brightening agents in the coating and in the paper base. The other half of papers did not use the optical

brightening agents at all. This subset of all ink-jet printed papers is sufficient to illustrate our observations.

As shown below, these papers are rougher than some glossy photo papers, but smoother than some matte coated ink-jet papers [22]. The second set represents a magazine grade coated free sheet; samples were printed by gravure printing process on the Cerutti Gravure Press at the Western Michigan University Printing Pilot Plant with four process inks: cyan, magenta, yellow, and black.

The samples names were assigned as follows:

- Ink-jet substrates with OBA: A1, A2, A3.
- Ink-jet substrates with no OBA: B1, B2, B3.
- Gravure substrates: C1, C2, C3.

Previous related work was done with larger set of ink-jet substrates [23], but a small set of data was sufficient for this study to demonstrate the findings from previous works and implement them with the gravure substrate set.

Porosity, roughness, and permeability

The Parker Print Surf (PPS) porosity and surface roughness/smoothness of the sheets were measured according to TAPPI T 555 "Roughness of paper and paperboard (Print-Surf method)" at different clamping pressures using a PPS tester. We calculated the permeability from the PPS porosity using the Pal equation derived from Darcy's Law [24].

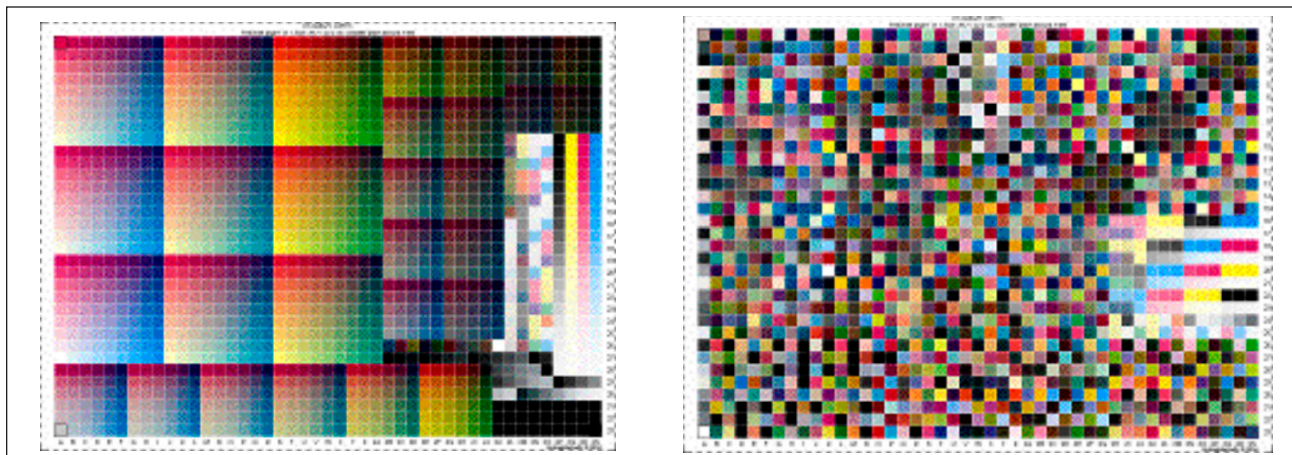
$$\text{Permeability, } K (\mu\text{m}^2) = 0.048838 * \text{Porosity, } Q (\text{mL/min}) * \text{Caliper, } L (\text{m}) \quad (1)$$

The PPS porosity was measured at 1000 kPa clamping pressure and the standard parameters for the PPS tester were set as follows [23]:

- Air viscosity = $1.801\text{E-}5$ Pa.s at 23°C.
- Standard pressure drop = 6.17 kPa.
- Cross-section area = 10 cm².

Brightness, whiteness, and opacity

TAPPI brightness and opacity were measured for all the substrates. TAPPI brightness is used as a measure of the reflectance



1. ECI 2002 Visual CMYK Target and ECI 2002 Random CMYK Target.

PRINTING

tance of papers at specific wavelength. The spectral and geometric conditions for TAPPI brightness are specified in TAPPI T 452, "Brightness of pulp, paper, and paperboard (directional reflectance at 457 nm)." Opacity is a measure of media ability to avoid penetration of light from one side to the other. Opacity is expressed as a ratio of the single sheet reading to a reference measure. The standard procedures are described in TAPPI T 425 "Opacity of paper (15 degrees/diffuse illuminant A, 89% reflectance backing and paper baking)." The CIE whiteness was calculated from X, Y, Z color data using the following equation [25]:

$$W_{CIE} = Y + 800(x_n - x) + 1700(y_n - y), \quad (2)$$

where: $x = X/(X+Y+Z)$,
 $y = Y/(X+Y+Z)$,
 $x_n = 0.3138$, and $y_n = 0.3310$ for $D_{65}/10$, 45/0 geometry.

Paper opacity and texture affect color reproduction [26]. We found that high opacity and microporosity are connected through the presence of fillers in the substrate or receptive layer. Higher opacity can be explained by the higher light scattering potential of paper fillers. These fillers also show an increase in paper microporosity [27].

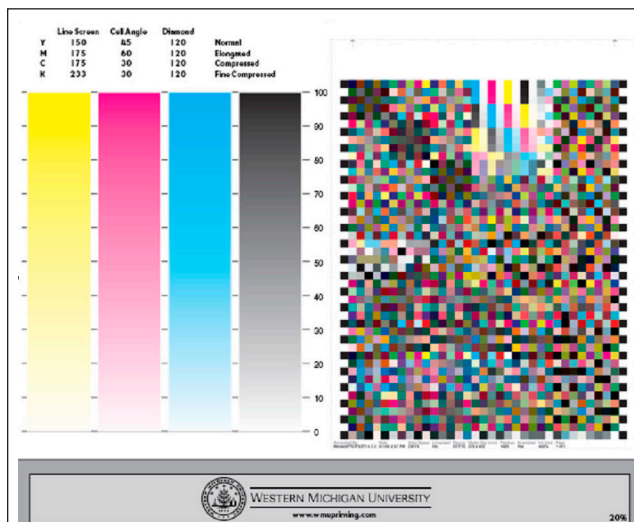
Color gamut

To obtain a large amount of data, we used the ECI 2002 Random CMYK Chart (Fig. 1). In the case of the gravure samples, the ECI 2002 Random CMYK Chart was included in the layout of the cylinders (**Fig. 2**).

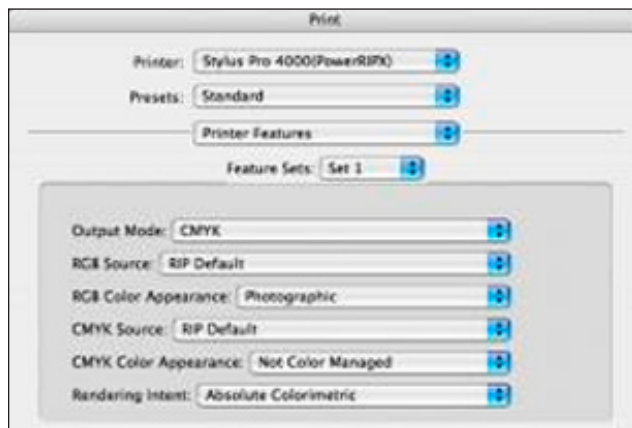
PRINTING PROCESS

Ink-jet substrates

All ink-jet substrates were printed on an Epson Stylus Pro 4000 printer, which employs seven color-pigmented inks: CcMmYKk. The ECI 2002R Chart was displayed in Adobe Photoshop and sent with no color management settings applied through a Pow-



2. ECI 2002R CMYK target on gravure cylinder layout.



3. Printer's setup.

erRIPX raster image processor (RIP) to the printer (**Fig. 3**). No linearization of the printer was conducted because the process did not improve the final print quality and might even decrease the amount of ink deposited on the media and thus alter the total color gamut that could be obtained [28].

Because all the substrates were art papers with receptive layer coatings, stochastic screen printing was used. Ink levels were set to 400% and resolution to 1440 dots per inch (dpi), as it would be set for a premium glossy photo paper, to ensure high ink load. The conditions were kept the same for all of the paper substrates in the experiments. The printed samples were analyzed in terms of $L^*a^*b^*$ values.

Gravure substrates

The gravure substrates were printed on a Cerutti press at 1000 ft/min. The conditions of the press were kept constant during the trial run. The densities were set to fall in the range $C = 1.35$, $M = 1.35$, $Y = 0.95$, and $K = 1.5$. Specific data for the cylinders were as follows:

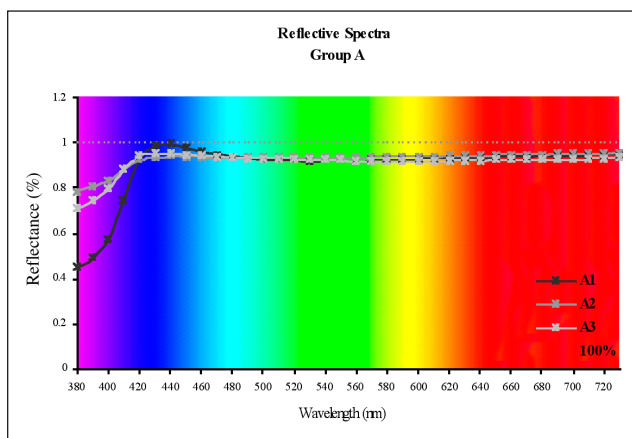
	Line Screen	Cell Angle	Cell Shape
Y	150	45	Diamond - Normal
M	175	60	Diamond - Elongated
C	175	30	Diamond - Compressed
K	233	30	Diamond - Fine Compressed

The ECI 2002R CMYK chart was measured, all the 1485 patches of the chart were read by an automated spectrophotometer (a Gretag Macbeth SpectroScan), and the data were collected to calculate the ICC profile. Because the instruments used to measure the substrate properties and the spectral data had 45/0 geometry, gloss has been excluded from the list of considered effecting factors. This configuration produces maximum gloss rejection and is preferred for glossy samples, such as graphic art work or publications [30]. The color gamut was calculated with CHROMiX ColorThink Pro 3.0. This software also was used as a tool for 3-D color gamut comparison at different L^* values.

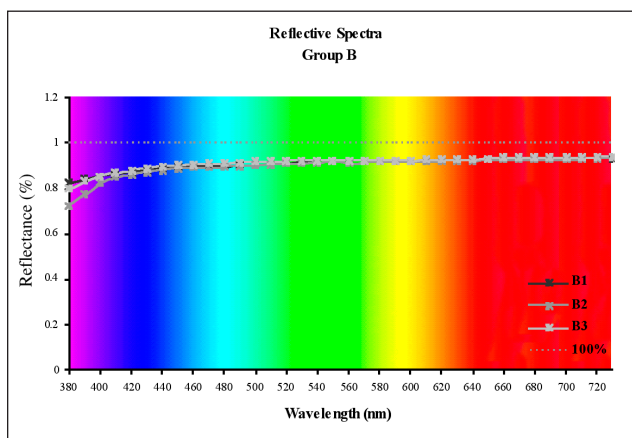
RESULTS AND DISCUSSION

OBA presence test

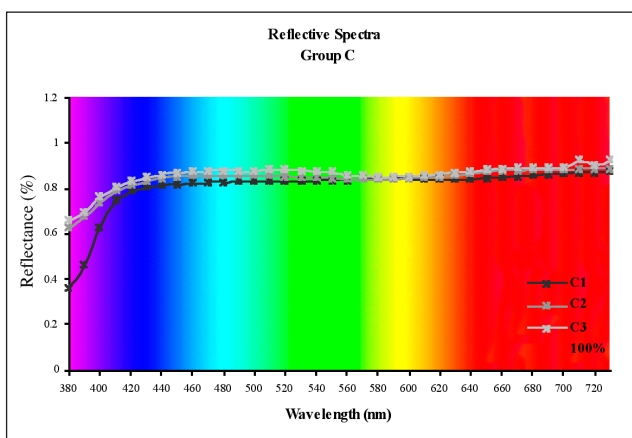
All of the samples were submitted to the test by which the presence of OBA can be easily assessed. The spectral data of



4. Visible reflective spectra of ink-jet samples with optical brightening agents A1, A2, and A3.



5. Visible reflective spectra of ink-jet samples without optical brightening agents, B1, B2, and B3, respectively.



6. Visible reflective spectra of gravure samples without optical brightening agents, C1, C2, and C3, respectively.

the substrates were measured with a spectrophotometer under $D_{50}/2^\circ$ geometry with no UV filter applied. That means all of the UV energy was included in the illumination and thus could be transmitted by OBAs to the higher wavelengths, which will show up as a higher peak in the blue region of the visible spectrum [4]. **Figures 4-6** show the spectra of all ink-jet and gravure samples.

The first set of ink-jet substrates appears to confirm the

Paper	PPS Porosity (mL/min)		Roughness (microns)	Caliper (mm)	Permeability μm^2
	500 CP	1000 CP			
A1	207.1	191.8	8.45	0.5175	0.0048
A2	998	936.3	8.56	0.6993	0.0319
A3	786.6	757.8	8.75	0.4392	0.0162
B1	111.3	102.7	8.24	0.3198	0.0016
B2	119.3	113.3	6.03	0.2961	0.0016
B3	4.09	1.08	7.1	0.4821	2.5E-05
C1	4.72	4.26	1.2	0.0747	1.55E-05
C2	2.43	2.04	1.13	0.0779	7.76E-06
C3	3.75	2.94	1.19	0.0816	1.17E-05

I. Parker Print Surf (PPS) porosity, roughness, and permeability results.

Paper	TAPPI brightness	CIE whiteness	TAPPI opacity (%)
A1	93.6	93.1	98.3
A2	93.6	88.9	98.9
A3	94.2	92.3	97.5
B1	90.6	80.9	95.8
B2	90.1	79.6	96.3
B3	90.9	82.2	98.0
C1	93.8	94.4	99.6
C2	90.9	92.5	99.1
C3	84.7	83.0	92.1

II. Brightness, whiteness, and opacity results.

existence of OBAs in the receiving coating layer. None of the gravure samples showed an apparent peak in blue region of visible light. There was no type of OBA in these substrates.

Porosity, roughness, and permeability results

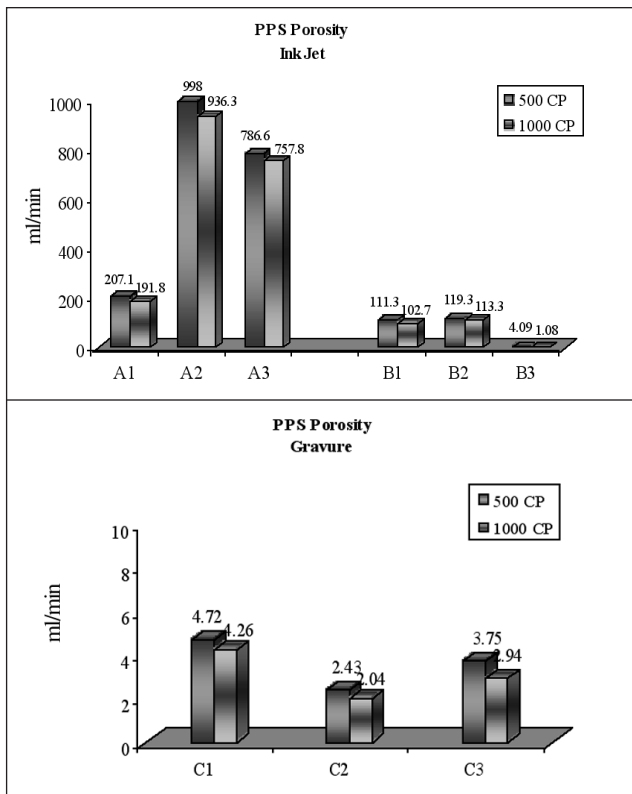
Table I and **Figs. 7-9** demonstrate the data collected from the measurements. It is evident that sample A2 has the highest permeability coefficient and PPS porosity, which is sensitive to permeability, but gives no measure of available pore space. The lowest values were found for sample B3, which had almost no flow capability. The value of the permeability coefficient indicates a flow controlling pore size of 5 nm. The least rough or the smoothest ink-jet substrate was the sample B2, followed by sample B3.

In the case of gravure substrates, the highest PPS porosity medium was sample C1, which also had highest permeability coefficient. Sample C2 was the smoothest substrates from the whole set.

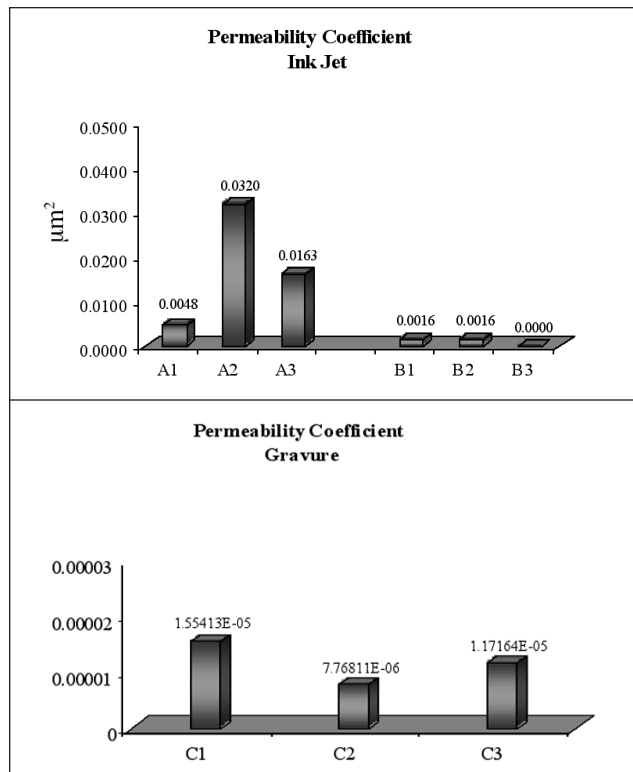
Brightness, whiteness, and opacity results

The results from all the tests are graphically presented in **Figs. 10-12** and relevant data are shown in **Table II**.

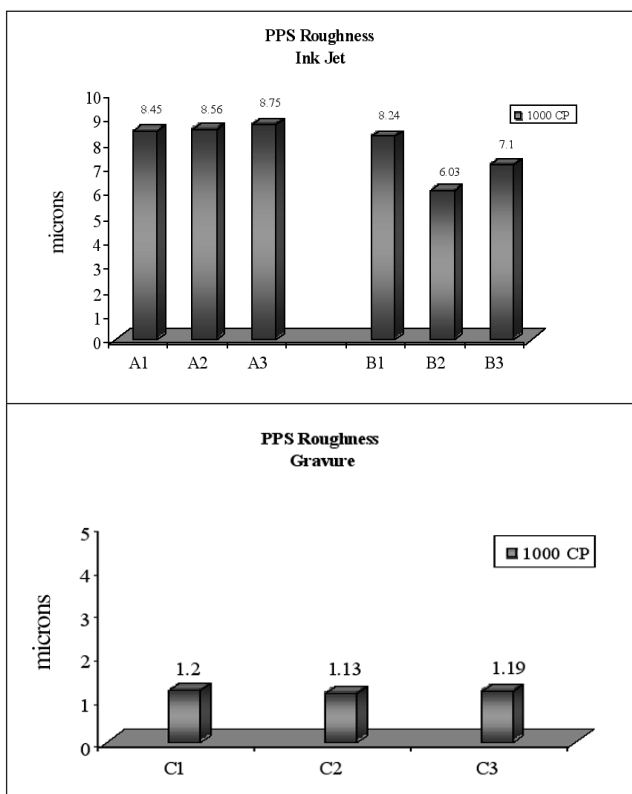
The substrates showed different maxima for different tested substrates, the brightest being A3, the whitest paper being A1, and the most opaque being A2. As expected, the set of substrates that contained optical brightening agents showed higher values for brightness and even more visible differences



7. Parker Print Surf porosity at 500 kPa and 1000 kPa for ink-jet substrates and gravure substrates, respectively.



9. Permeability calculated from Parker Print Surf porosity measured at 1000 kPa for ink-jet substrates and gravure substrates, respectively.



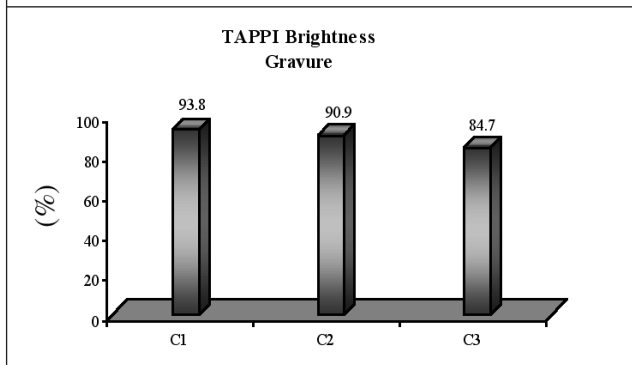
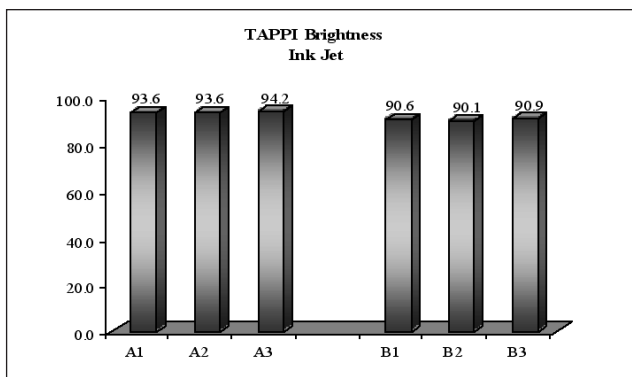
8. Parker Print Surf roughness at 1000 kPa for ink-jet substrates and gravure substrates, respectively.

within whiteness values. Sample C2 from the gravure substrate set had the highest brightness, whiteness value, and highest opacity. All the ink-jet samples were brighter papers and had higher opacity levels compared to the gravure samples.

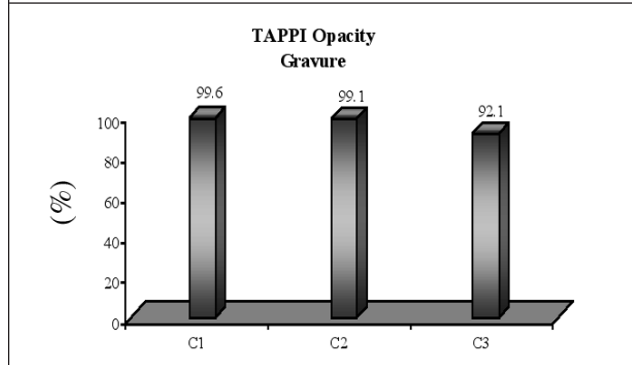
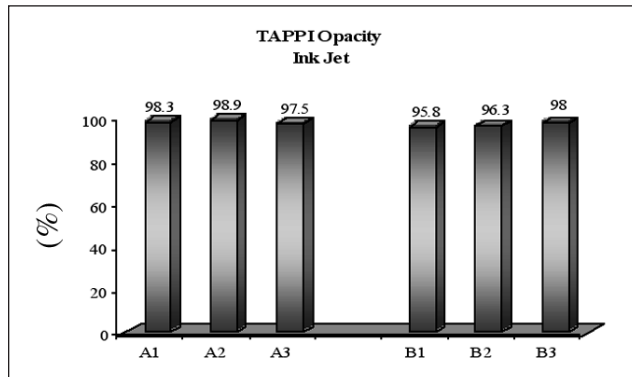
How do we decide on the best substrate for our purpose now? It looks quite difficult to make the decision based on the information we gathered from the optical and physical tests done on all the substrates. What if we had one more tool that would immediately tell us which of all the substrates will provide the most exceptional properties? That tool would be the color gamut volume number.

Color gamut volume

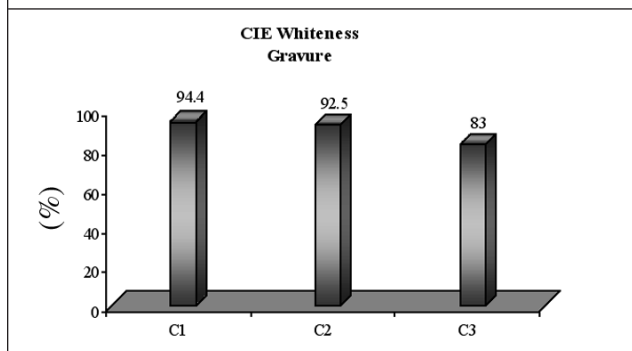
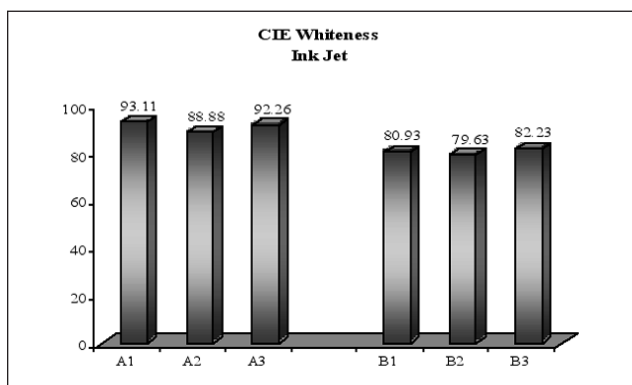
Figure 13 shows the color gamut volume of all the ink-jet substrates printed with the same pigment-based ink set under the same conditions. The color gamut volume, a volume in CIELab space, can be interpreted as the number of colors that are discernable within a tolerance of $\Delta E = \sqrt{3}$. Thus, the highest number of colors that could be produced by our specific ink-jet printer and pigmented ink set was achieved using substrate B3, closely followed by substrate B2. Surprisingly, there is no correlation between the optical performance of the substrate and the ability to reach the highest possible ink level to obtain more vivid and colorful prints. On the other hand, color gamut does seem to correlate with permeability, that is, the less permeable the substrate, the higher the color gamut volume that can be achieved. Also, the smoothness of



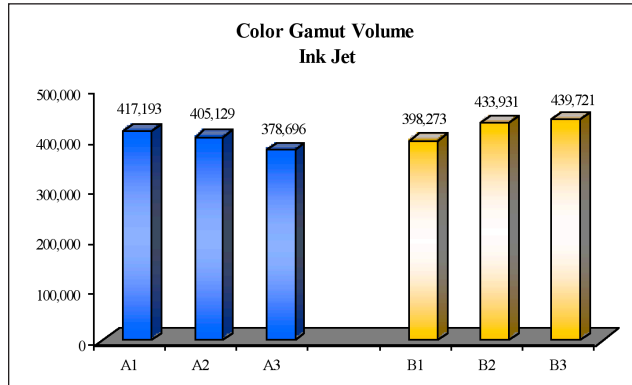
10. TAPPI brightness for ink-jet substrates and gravure substrates, respectively.



12. TAPPI opacity for ink-jet substrates and gravure substrates, respectively.



11. CIE whiteness for ink-jet substrates and gravure substrates, respectively.



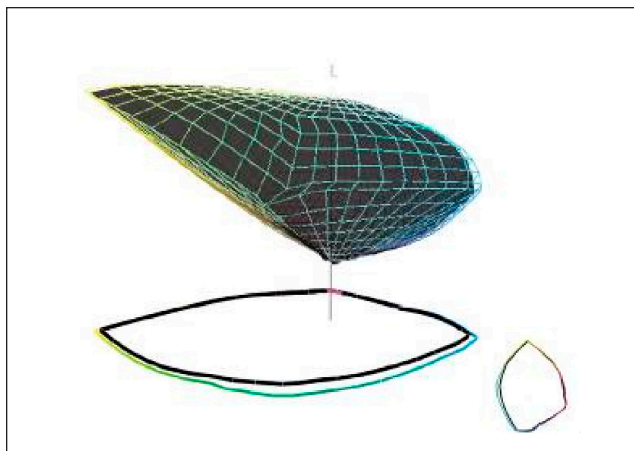
13. Color gamut volume for ink-jet optical brightening agents (OBA) (A1-3) and OBA-free (B1-3) substrates, respectively.

= 417,193 and B3 = 439,721) in their respective groups (OBA and OBA-free substrates). The 3-D plot is shown to provide the geometrical representation of the gamut boundary differences (**Fig. 14**).

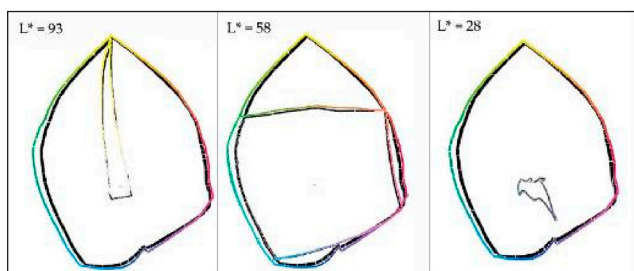
The 3-D plot and 2-D projection definitely supports the fact that the B3 sample reaches the higher gamut volume. In the 3-D plot the black boundary of A1 sample is all included within the true color wireframe boundary of the B3 sample.

To analyze the color gamuts more closely, one has to look very precisely at the plots showing different lightness values. Different levels of L^* , lightness value, prove the presence of OBA and different performance of the ink-jet ink on different substrates as shown in Fig. 14.

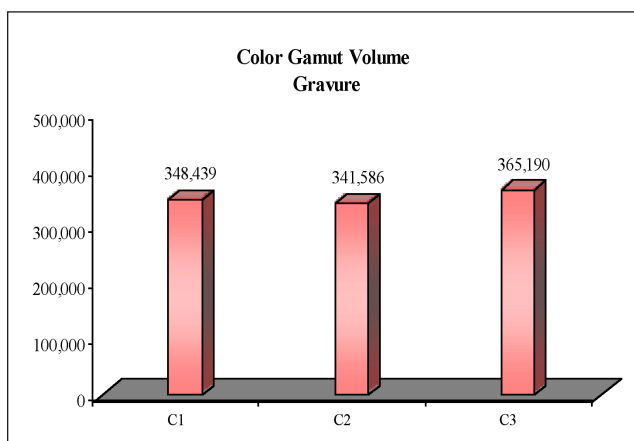
the substrate can play an important role in the way ink-jet pigment-based ink is placed on top of the receptive coating layer. In addition, we compared two different substrates, A1 and B3. These samples reached the highest gamut volume values (A1



14. Two- and three-dimensional gamut comparison for optical brightening agent (OBA) sample A1 (black solid) and OBA-free sample B3 (true color wireframe).



15. Color gamut boundary projection at different L^* values; high-lights ($L^*=93$), midtones ($L^*=58$) and shadows ($L^*=28$), respectively. Optical brightening agent (OBA) free substrate (true color) and OBA included substrate (black) 2D



16. Color gamut volume for gravure substrates.

The lightest areas (**Fig. 15**), $L^*=93$, clearly show the shift of the color gamut toward the yellow region for the OBA-free papers and the shift toward the blue region for OBA papers. At mid-tones, the color gamut projection does not show any significant discrepancies or shifts. As predicted, the darker colors, $L^*=28$, can be reached with the OBA-free substrates (Fig. 15), because the whiter paper moves the gamut toward the lighter colors. This might be the reason why OBA-free

papers are able to display a larger number of colors.

Figure 16 shows the gamut volume values for three gravure magazine grade substrates printed by gravure. The highest color gamut volume was obtained for substrate C3 printed on the gravure press. Evidently, there is no correlation between the optical properties of the substrate and the size of gamut volume, because the results from all the tests showed that the sample C3 did not reach highest or lowest values within the measured characteristics.

CONCLUSIONS

This work presents a new way for evaluation of a substrate that will be used in a given printing process. We are able to establish which substrate or ink set will perform better or worse by looking at the combination of substrates and inks in terms of color profile and color gamut volume. We decided to pick different substrates, high-end fine art ink-jet papers with matte finish and gravure magazine grade media, to show how the substrate properties do or do not affect the overall final presentation of the prints.

The results presented in this work show there is no clear correlation between the optical properties of the substrate (e.g., brightness, whiteness, and opacity) and the specific range of colors that can be produced on such substrates.

We verified that the presence of optical brightening agents, which are responsible for a whiter look of the substrate, do not necessarily produce higher color output. The optical properties of the substrate do not play the main role in color reproduction level. In the case of ink-jet substrates, the smoother and less permeable substrate can reach the highest values of colors printed. This could be explained by a thicker ink layer deposited on the top of a coated sheet, because of the less permeable substrate characteristics. A closer look at the gamut projection shows that less bright and white substrates could reach more colors in darker areas as well.

Surprisingly, the gravure samples showed no evident correlation between any of the properties, optical or physical, and the size of the gamut volume.

The results from this work make us ask again: What substrate properties are the important ones? How far do we have to go to obtain the best results? **TJ**

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LITERATURE CITED

1. Preucil, F.M., *TAGA Proceedings 1962*, Technical Association of the Graphic Arts, Sewickley, Pennsylvania, USA, pp. 227-234.
2. Zawacki, W.F. and Steele, L.C., *TAGA Proceedings 1999*, Technical Association of the Graphic Arts, Sewickley, pp. 135-147.
3. Yang, L. and Kruse, B., *TAGA Proceedings 2001*, Technical Association of the Graphic Arts, Sewickley, pp. 399-407.
4. Nörberg, O. and Andersson, M., *Proceedings of the IS&T NIP 19*, Society for Imaging Science and Technology, Springfield, Virginia, USA, 2003, pp. 836-840.
5. Klamann, M. and Andersson, L., *Proceedings of the 1999 TAGA 51st Annual Technical Conference*, Technical Association of Graphic Arts, Rochester, pp. 338-358.
6. Klamann, M., J.A.: *Advances in Printing Science and Technology*, 26:255 (2000).
7. Crouse, B.W. and Snow, G.H., *Tappi J.* 64(7): 87(1981).
8. Springsteen, A.W., "Fluorescence & color," a monograph, Labsphere, Inc., North Sutton, New Hampshire, USA, 2003.
9. Evans, M., *Gravure*, 17(2): 62(2003).
10. International Commission on Illumination (CIE), *Recommendations on uniform color spaces, color-difference equations, psychometric color terms*, Supplement No. 2, CIE Pub. No. 15 (E-1.3.1), 1971 (TC-1.3), Bureau Ventral de la CIE, Paris, France, 1978.
11. Berns, R.S., *Billmeyer and Saltzman's Principles of Color Technology*, 3rd edn., Wiley-Interscience, New York, New York, USA, 2000.
12. Cholewo, T.J. and Love, S., *Proceedings of the IS&T/SID 1999 Seventh Color Imaging Conference: Color Science, Systems and Applications*, Society for Imaging Science and Technology, Springfield, pp. 200-204.
13. Saito, R. and Kotera, H., *Proceedings of IS&Ts NIP16, 2000 International Conference on Digital Printing Technologies*, Society for Imaging Science and Technology, Springfield, pp. 566-569.
14. Braun, G.J. and Fairchild, M.D., *IS&T/SID Fifth Color Imaging Conference: Color Science, System and Applications*, Society for Imaging Science and Technology, Springfield, 1997, pp. 147-152.
15. Kang, H.R., *Proceedings of IS&T's 2003 NIP19 International Conference on Digital Printing Technologies*, Society for Imaging Science and Technology, Springfield, pp. 808-812.
16. Herzog, P.G., *J. Imaging Sci. Tech.* 40(6): 516(1996).
17. Herzog, P.G. and Hill, B., *Proceedings of the Third IS&T/SID Color Imaging Conference: Color Science, Systems and Applications*, Society for Imaging Science and Technology, Springfield, 1995, pp.78-81.
18. Berns, R.S., *Color Res. Applic.* 22(5): 318(1997).
19. Sharma, A., *Understanding Color Management*, Delmar Thomson Learning, Florence, Kentucky, USA, 2004.
20. Engeldrum, P.G., *Proceedings of the 1986 SID Conference, Society for Information Display*, 27:11, pp. 25-30.
21. European Color Initiative, *New 'ECI 2002' target and conversion tools*. Available at <http://www.eci.org/doku.php?id=en:projects:eci2002>.
22. Xu, R., Fleming, P.D., Pekarovicova, A., et al., *J. Imaging Sci. Technol.* 49(6): 660(2005).
23. Chovancova-Lovell, V. and Fleming, P.D., *Proceedings of the IS&T NIP22: 2006 International Conferences on Digital Printing Technologies*, Society for Imaging Science and Technology, Springfield, pp. 227-230.
24. Pal, L., Joyce, M.K., and Fleming, P.D., *TAPPI J.* 5(9): 10(2006).
25. International Commission on Illumination, *CIE 15:2004, Colorimetry*, 3rd edn., Vienna, Austria, 2004.
26. Monaco, R., "Looking to improve color? Improve quality first" *Newspapers & Technology*, September 2004, Available at http://www.newsandtech.com/issues/2004/09-04/pt/09-04_monaco.htm.
27. Lauffman, M., *Wochenbl. Papierfabr.* 133(11-12): 622(2005).
28. Hrehorova, E., Sharma, A., and Fleming, P.D., *Proceedings of the 2006 TAGA 58th Annual Technical Conference*, Technical Association of the Graphic Arts, Sewickley, pp. 159-171.
29. Mikula, M., Ceppan, M., and Vasko, K., *Color Res. Applic.* 28(5): 335(2003).

INSIGHTS FROM THE AUTHORS

This work represents part of the color research projects we have been involved with for many years. We feel that the results can provide an additional way to characterize a substrate for any printing project.

Precise measurement and control of the printing and press conditions are very important to this research. The most remarkable thing about this work is that tools never before used in certain areas can be accommodated, and help provide new ways for assessing the product properties.

We feel this research is useful because testing and looking at the final products (gamuts that are possibly reachable on specific substrates) can help guide production personnel. We plan to continue our work in color research.



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