How Paper Properties Influence Color Reproduction of Digital Proofs for Publication Gravure

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Abstract

Gravure is the major printing process used for publication such as long-run magazine, catalogs, newspaper, and miscellaneous commercial printing. In gravure printing processes, color proofing is for the purpose of checking the color to ensure that it is as desired, before proceeding to cylinder engraving. Recently, the use of inkjet digital proofing gained popularity due to its benefits of high speed, wider color gamut, and affordable prices for a device. Proofing on the actual production stock more closely predicts print outcome. However, paper properties have significant effect on the image reproduction for proofing processes. Working with different inks and devices, the actual production printing substrate can have a very different color gamut and behave differently in the digital proofing process.

The color capability of a digital proofing system influences color gamut and performance, which in turn affects accuracy of color for the press to match. This study discusses the color reproduction of digital proofing from the point of view paper properties. Publication printing substrates and manufacturer recommend proofing paper were tested on the Epson Stylus Pro 4000 printer and Xerox Phaser 8550 printer. Paper surface properties (roughness, porosity, pore size, formation) and optical properties (brightness, whiteness, opacity, and gloss) were tested.

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1. Introduction

In gravure printing processes, similar to all other printing processes, color proofing for the purpose of checking the color to ensure that it is as desired, is becoming a must, especially in the field of catalog publishing. In the past, proofing was done by using a gravure proof press with higher cost. Digital proofers have the advantages of high speed, wide color gamut, and affordable prices for a device; therefore, providing significant time and cost savings compared to conventional gravure proofs.

Generally, proofing is done using the substrate that will be used for actual product printing. When the digital printer is to be used for proofing, the substrate characteristics have to be taken into the account (Wales, 2004; Norberg & Andersson, 2003; Bandyopadhyay, 2001). These characteristics may differ significantly from the ideal/manufacturer recommended substrate. Digital proofing systems work with spectral characteristics of the colorants and the printed results could be different from a printing press. The color gamut of a particular combination of printer, ink, print media, and RIPs is determined by the uniformity of ink absorbency and color density. Color gamut in turn represents the color fidelity and color matching results. A digital proofing system with wider color gamut is desirable to provide better color reproduction capability for proof-press color matching.

The color gamut of a digital proofing system is affected by the printer, software and substrate involved in digital proofing processes (Suchy et al, 2005; Suchy et al, 2007; Wu, et al, 2006; Wu, et al, 2007). Paper properties are probably the most important factors affecting the completeness of the image transfer and image appearance in all color reproduction processes. As a crucial variable in predicting and reproducing color, paper has significant influence on the print quality, such as print contrast, density, color and tonal range, and surface uniformity. The interaction between paper and ink, its porosity, roughness, together with optical properties such as whiteness, opacity, light scattering, and gloss (Lee et al, 2004, 2005) must be considered in the printing process.

The printability of a paper surface is influenced by surface properties such as smoothness, uniformity and the paper's absorption of the ink (Wilson, 1997). In general, high print quality is associated with good formation and with smooth, compressible paper (Thompson, 1998). The most important surface properties of paper include roughness, formation, porosity and permeability. Roughness and formation are considered as external surface properties, while pore size, porosity and permeability are categorized as internal surface properties. Roughness affects ink gloss and color, as well as print contrast. Formation is an indicator of how uniformly the fibers and fillers are distributed in the sheet. Formation plays an important role as most of the paper properties depend on it. A poorly formed sheet will have more weak and thin or thick spots. Paper formation will affect the printing characteristics of the paper (Biermann, 1996; Peel, 1999; Wilson, 1997). The porosity of a paper sheet is the ratio of pore volume to total volume and it greatly affects properties such as hardness, compressibility, resiliency, and the ability to absorb inks. Most uncoated printing and writing papers are considered moderately porous, whereas coated printing papers are relatively nonporous. Air permeability is defined as the property of a paper that allows air to flow through it under a pressure difference across the sheet. The air permeability is an indicator that shows how printing inks will penetrate and spread (Wilson, 1997; Scott & Abbott, 1995).

The optical properties of a paper influence the visual quality of the printed image and contribute to its appearance and appeal. The best color reproduction will occur with papers that are bright with uniform spectral reflection, smooth, glossy, and neutral shade (Wales, 2004). The optical properties include gloss, opacity, whiteness, brightness, and paper color. Brightness is defined as the percentage reflectance of blue light at a wavelength of 457 nm. Whiteness refers to the extent that paper diffusely reflects light of all wave lengths throughout the visible spectrum. Brightness and whiteness are important for print contrast characterization. The higher the brightness or whiteness, the higher the contrast between the paper and printed image is (Lee et al, 2003). Opacity is a measure of a paper's ability to obstruct the passage of light. Too much show-through of printed images from the back side of the sheet will reduce print contrast and interfere with the visual appearance of the image. Gloss is the attribute of paper surface that makes the images look shiny or lustrous. The gloss of a paper affects the color of a print because it affects the way light is reflected through the ink. In order to maintain uniform color printing throughout a job, the variations in gloss must be monitored and kept to a minimum level. Glossy papers are usually associated with high surface smoothness and good printing quality. High quality printed images also come up with high gloss by increasing the gloss of printed ink films and enhances the brilliance and color intensity of printing (Levlin & Soderhjelm, 1999; Wilson, 1997; Thompson, 1998).

In order to achieve uniformity of printing and obtain good color reproduction performance for the digital proofing system, it is important that the all paper properties are well defined and controlled (Thompson, 1998).

2. Methodology

The proof-press color matching highly depends on the range of colors and tonal ranges that digital printers can reproduce and also how accurately these color numbers can be manipulated in comparison to printing characteristics. The former is determined by ink-paper interaction of a digital printer and the latter needs the aid of color management. Before performing proof-press color matching, the color gamut of print combination of digital proofing system must be well defined. Understanding the relationship between paper properties and color gamut can help to predict and control color gamut in the digital proofing system.

2.1. Equipment and Materials

The ECI2002R CMYK test target designed for DTP 70 spectrophotometer was employed for this study. The patches of the target chart are specially designed to produce a good distribution of colors in L*a*b* space.

Three gravure publication printing substrates- free sheet coated paper, light weight coated paper, and newsprint- were selected as the actual production printing substrates. Furthermore, three types of manufacturer recommended proofing papers- semimatte photo paper, pearl proof paper, and selected proof paper were tested and compared. Table 1 provides basic information of substrates used in this study. Basis weight is the mass per unit area of the paper (denote as g/m^2), whereas caliper is the thickness of the paper sheet (denote as µm). Proofing papers have heavier basis weight and tend to be thicker than the gravure publication printing papers.

Table 1: Selected properties of tested substrates

Substrates	Basis Weight [g/m^2]		Caliper [µm]	
	Mean	Std. Dev.	Mean	Std. Dev.
Free Sheet	66.70	0.64	58.93	2.91
Light Weight Coated	50.38	0.77	46.87	2.42
Newsprint	49.39	0.33	72.57	3.04
Semimatte Photo Paper	255.44	0.94	258.49	2.15
Pearl Proof Paper	237.84	0.83	235.21	2.79
Selected Proof Paper	192.07	0.70	184.15	2.31

Two commercially available digital printers were selected as digital proofing devices: an Epson Stylus Pro 4000 printer with UltraChrome pigmented inks and a Xerox Phaser 8550 printer with hot melt inks. Epson Stylus Pro 4000 printer apply drop-on-demand technology to form droplets on the paper surface. The digital signal changes by heating or using a piezoelectric effect (Brett, 2001; Smyth, 2001). Xerox Phaser 8550 printer utilize hot melt ink rather than the liquid or dry ink used in other processes, but is actually also piezoelectric drop on demand ink jet printer.

2.2. Research Procedure

In order to analyze color gamut for a device, an ICC profile needs to be created. ICC profiles were generated for the Epson Stylus Pro 4000 and Xerox Phaser 8550, using selected gravure publication substrates and proofing papers. The devices were profiled as CMYK. For the Epson Stylus Pro 4000 printer, the ECI2002R CMYK chart was printed on the tested substrates via CGS ORIS RIP software. For the Xerox Phaser 8550 printer, the ECI2002R CMYK chart was printed on the tested substrates via its printer driver, which still is CMYK addressable as a PostScript device. Those printed charts were measured with a X-Rite DTP70 spectrophotometer, operated by GretagMacbeth Measure Tool 5.0.7 software. The measurement files were used to generate profiles using

GretagMacbeth ProfileMaker Pro 5.0.7. ICC profiles were then loaded into CHROMiX ColorThink Pro 3 software and the gamut volume of ICC profiles were determined.

2.3. Data Collection and Analysis

Ten printed ECI2002R CMYK charts were collected for each substrate. The data of surface properties (roughness, porosity, permeability, pore size, and formation) and optical properties (whiteness, brightness, opacity, and gloss), together with gamut volumes for selected six tested substrates were collected and the relationship between paper properties and color gamut (gamut volume) were studied. The color gamuts of proofing devices v.s. gravure press were compared using ColorThink Pro 3.0 software. The color gamut of press was acquired from the paper printed on a Cerutti rotogravure web press, located at Western Michigan University (WMU) Printing Pilot Plant. The instruments used for paper properties measurement and sample sizes were summarized in Table 2.

Table 2: Instruments used for paper properties measurement

Paper Properties	Measuring Instrument	Sample sizes for each paper
Roughness [μm]	EMVECO stylus profilometer	10
Permeability [μm^2]	Parker Print-Surf (PPS) tester Using equation of K = 0.048838 * Q * X Q=PPS Porosity; X=thickness	10
Pore size [nm]	Mercury intrusion porosimetry	1
Porosity [%]	Mercury intrusion porosimetry	1
Formation	M/K system formation tester	10
Brightness [%]	Brightimeter MICRO S-5 (C/2°)	10
Whiteness [%]	Brightimeter MICRO S-5 (ASTM standard, C/2°)	10
Opacity [%]	BNL-2 Opacimeter (TAPPI Standard)	10
Paper Gloss [%]	Novo-Gloss™ Glossmeter (at 75°)	10

3. Results and Discussion

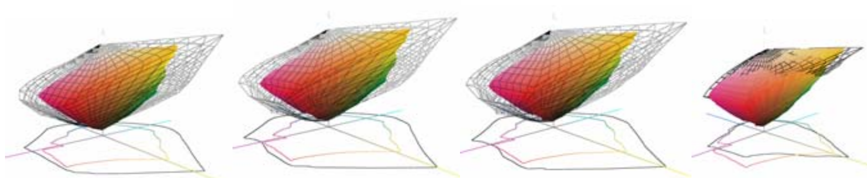
3.1. Color Gamut Comparison

The color gamut is the range of colors that a particular combination of printer, ink, print media, and RIP can achieve. The proof-press color gamut comparison for the free sheet (FS), light weight coated (LWC) and newsprint is discussed below.

Epson Stylus Pro 4000 Printer

When proofing on the free sheet with Epson Stylus Pro 4000 printer, it was found that UltraChrome inks have severe ink smearing problem and cannot lay on the paper surface properly. Therefore, free sheet coated paper with Epson Stylus Pro 4000 printer combination was excluded in the discussion.

Figure 1 illustrates the proof-press color gamut comparison for the light weight coated paper printed via Epson Stylus Pro 4000 printer. As expected, the color gamut of selected proofing papers – premium semimatte photo paper (PSPP), pearl proof paper (PPP), and selected proof paper (SPP) - was wider than that of light weight coated paper that was printed via the Cerutti rotogravure web press. When proofing on the light weight coated paper, however, the digital printer yielded wider color gamut in yellow area but smaller color gamut in magenta and red regions. The press gamut is larger in the lower L^* values area where digital printer cannot achieve the dark shadow details.



(a) proof (PSPP, black wireframe) v.s. press (LWC, true color)

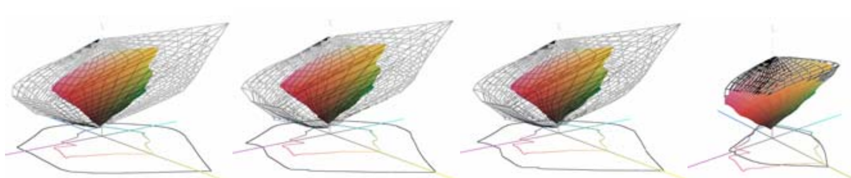
(b) proof (PPP, black wireframe) v.s. press (LWC, true color)

(C) proof (SPP, black wireframe) v.s. press (LWC, true color)

(d) proof (LWC, black wireframe) v.s. press (LWC, true color)

Figure 1: Proof-press color gamut comparison for the light weight coated paper printed via Epson Stylus Pro 4000 printer

The proof-press color gamut comparison for the newsprint printed via Epson Stylus Pro 4000 printer is shown in Figure 2**.** The color gamut of selected proofing papers was wider than that of newsprint that was printed via the Cerutti rotogravure web press. When proofing on the newsprint, the color gamut of digital printer is similar to that of press, with exception of red region. The Epson Stylus Pro 4000 printer gamut is larger in the higher L^* values area, while the press gamut is larger in the lower L^* values area.



(a) proof (PSPP, black wireframe) v.s. press (newsprint, true color)

(b) proof (PPP, black wireframe) v.s. press (newsprint, true color)

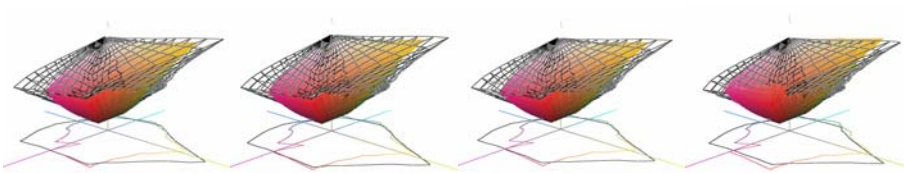
(C) proof (SPP, black wireframe) v.s. press (newsprint, true color)

(d) proof (newsprint, black wireframe) v.s. press (newsprint, true color)

Figure 2: Proof-press color gamut comparison for the newsprint printed via Epson Stylus Pro 4000 printer

Xerox Phaser 8550 Printer

Figure 3 illustrates the proof-press color gamut comparison for the free sheet coated paper printed via the Xerox Phaser 8550 printer. For proofing, whether on the proofing papers or free sheet coated paper, the digital printer tends to have a wider color gamut in yellow and magenta areas. The Xerox Phaser 8550 printer gamut is larger in the higher L^* values area, while the press gamut is larger in the lower L^* values area. There are some saturated colors that the press can achieve that the digital printer cannot, and vice versa.



(a) proof (PSPP, black wireframe) v.s. press (FS, true color)

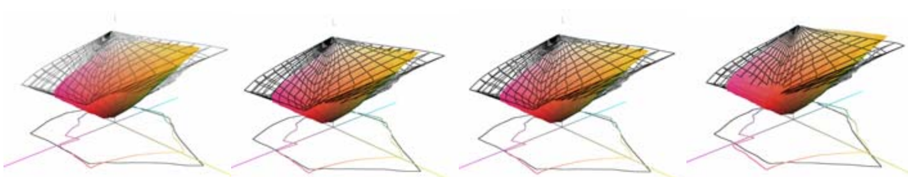
(b) proof (PPP, black wireframe) v.s. press (FS, true color)

(C) proof (SPP, black wireframe) v.s. press (FS, true color)

(d) proof (FS, black wireframe) v.s. press (FS, true color)

Figure 3: Proof-press color gamut comparison for the free sheet coated paper printed via Xerox Phaser 8550 printer

The proof-press color gamut comparison for the light weight coated paper printed via the Xerox Phaser 8550 printer is shown in Figure 4**.** Basically, the color gamut of digital printer is similar to that of press except for yellow and magenta regions. The Xerox Phaser 8550 printer gamut is larger in the higher L^* values area, while the press gamut is larger in the lower L^* values area. Again, there are some saturated colors that the press can achieve that the digital printer cannot, and vice versa.



(a) proof (PSPP, black wireframe) v.s. press (LWC, true color)

(b) proof (PPP, black wireframe) v.s. press (LWC, true color)

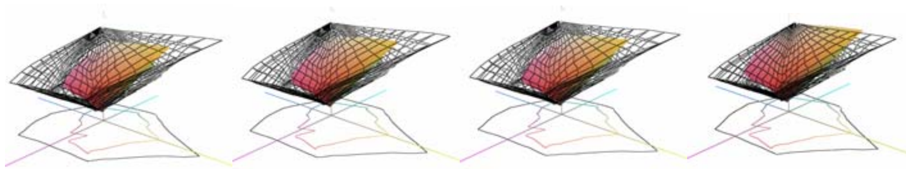
(C) proof (SPP, black wireframe) v.s. press (LWC, true color)

(d) proof (LWC, black wireframe) v.s. press (LWC, true color)

Figure 4: Proof-press color gamut comparison for the light weight coated paper printed via Xerox Phaser 8550 printer

Figure 5 displays the proof-press color gamut comparison for the newsprint printed via the Xerox Phaser 8550 printer. As shown in Figure 5, proofing whether on the proofing papers or printing substrate, the color gamut of digital printer is larger than that of press. This was actually expected, because hot melt ink solidifies fast, prior to being able to absorb into porous newsprint sheet.

Table 3 shows the proof-press color gamut comparison in terms of gamut volume. Comparing to press gamut volume, Epson Stylus Pro 4000 printer has larger gamut volume for the selected proofing papers but smaller gamut volume for the actual production printing substrates. Xerox Phaser 8550 printer, however, produces larger gamut volume for proofing and printing substrates, with exception of light weight coated paper. Working with different ink technology, the gamut volume of Epson Stylus Pro 4000 printer is larger than that of Xerox Phaser 8550 printer for the selected proofing papers.



(a) proof (PSPP, black wireframe) v.s. press (newsprint, true color) (b) proof (PPP, black wireframe) v.s. press (newsprint, true color) (C) proof (SPP, black wireframe) v.s. press (newsprint, true color) (d) proof (Newsprint, black wireframe) v.s. press (newsprint, true color)

Figure 5: Proof-press color gamut comparison for the newsprint printed via Xerox Phaser 8550 printer

Table 3: Gamut volumes comparison for recommended and printing substrates

Substrates	Cerutti Rotogravure Web Press	Epson Stylus Pro 4000 Printer	Xerox Phaser 8550 Printer
Free Sheet	331,854	----------	336,500
Light Weight Coated	317,645	218,976	309,278
Newsprint	149,459	123,462	264,869
Semimatte Photo Paper	----------	700,148	420,823
Pearl Proof Paper	----------	684,436	400,395
Selected Proof Paper	----------	698,918	408,959

3.2. Paper Properties

Roughness Measurement

Roughness is one of the most important factors affecting print quality. A smoother surface can result in a good ink transfer, and vice versa. The Electronic Microgage Model 210-R (Emveco, Inc) with the spherical steel stylus having a radius of 1 µm was used for profilometer measurement. The test conditions were 500 readings per group, 3 groups, 0.1 mm reading space, and 0.5 mm/s scanning speed. The roughness R was then calculated using (Xu, et al., 2005):

$$R = \quad | X_{i+1} - X_i | /499, \; i = 1,2,\ldots,499 \qquad (1)$$

Roughness measurements of tested substrates are shown in Table 4 and Figure 6. Generally, proofing papers have a smoother surface. The average roughness readings for the proofing papers are in the range of 0.7 to 1.2 micron. Compared to other papers, newsprint tends to have rougher surface and a larger standard deviation value. As shown in Figure 6, the surface of proofing papers is smoother than that of printing papers.

Table 4: Roughness measurement

Substrates	Emveco roughness [µm]	
	Mean	Std. Dev.
Free Sheet	0.96	0.12
Light Weight Coated	1.38	0.14
Newsprint	3.03	0.13
Semimatte Photo Paper	1.06	0.05
Pearl Proof Paper	0.78	0.06
Selected Proof Paper	1.13	0.08

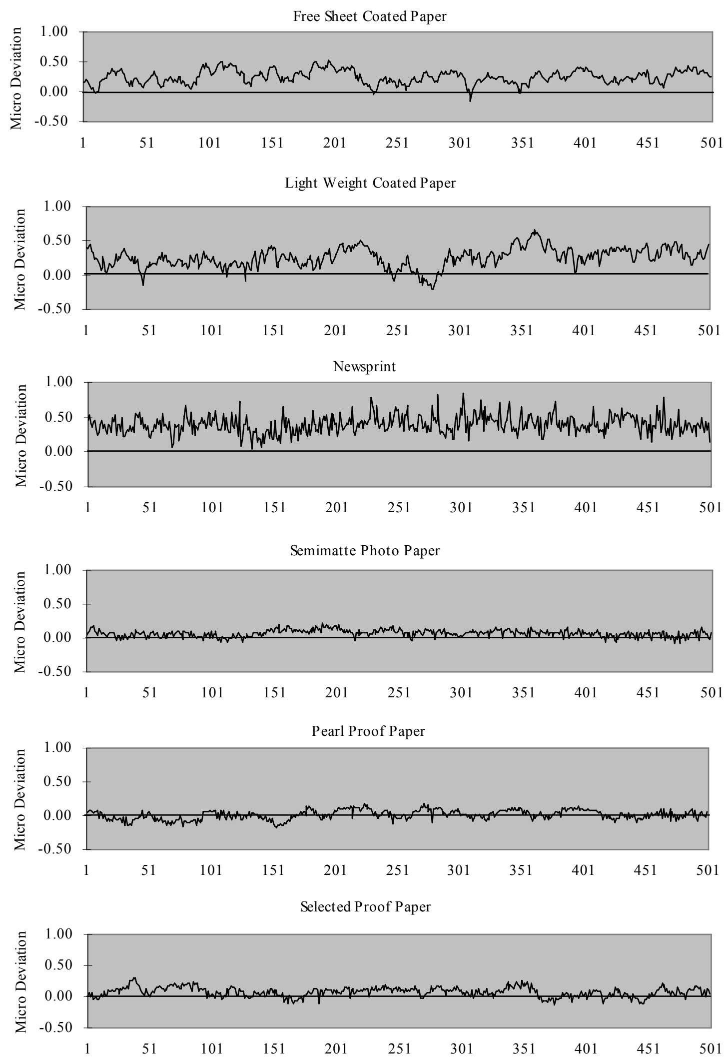


Figure 6: Emveco roughness profile of tested papers

Formation Measurement

Formation is a measurement of uniformity of the paper (Wilson, 1997). A formation index is used to evaluate formation, which measures the relative uniformity of paper on the basis of localized variations in basis weight. A M/K system formation tester was employed to obtain formation index values which measure variations in light transmitted through the tested sheet as the light source scans across the sheet rapidly. Each measurement is amplified and stored in one of 64 optically measured "basis weight" classes or memory bins. The greater the deviation in optical density from the instantaneous average, the further away a given data point is stored from the central bin or average weight class of the histogram. At the end of each scan, the number of contiguous bins and the amplitude or peak height of the histogram were recorded. The formation index was calculated based on the equation of:

$$\text{Formation Index} = \text{Peak Height} / \text{No. of Bins} * 1/100 \qquad (2)$$

The more uniform a sheet, the greater its peak height is, and the fewer the number of bins into which the data fall. In other word, the larger the formation index, the more uniform the sheet. Table 5 displays the formation index measurement of tested substrates. It shows that proofing papers are more uniform than printing paper. It is interesting to note that light weight coated paper has poor formation. The uniformity of newsprint used in this study is better than that of light weight coated paper.

Table 5: Formation index measurement

Substrates	Formation Index	
	Mean	Std. Dev.
Free Sheet	104.83	4.31
Light Weight Coated	11.82	0.90
Newsprint	120.26	3.06
Semimatte Photo Paper	318.33	0.53
Pearl Proof Paper	212.06	4.03
Selected Proof Paper	259.31	2.92

Pore Size and Volume Measurement

An Autopore IV 9500 mercury porosimeter, measuring the incremental increase of volume penetrated as the pressure rises, was employed for the porosity-related characteristics measurement such as of pore size, volume, and distribution of a paper. The pressure required to intrude mercury into the sample's pores is inversely proportional to the size of the pores. Paper samples were placed in a penetrometer and evacuated at 50 μm Hg (Hrehorova, et al., 2005).

Table 6 shows that the highest percent porosity was found in newsprint with 61.43%, followed by light weight coated (59.77%), free sheet (41.27%), pearl proof paper (37.25%), and semimatte photo paper (36.66%). Selected proof paper has the lowest percent porosity at 26.39%. The average pore size readings for the proofing papers are in the range of 25 to 50 nm, whereas the average pore size readings for gravure publication printing papers are larger than 200 nm. The average pore size of newsprint is up to 545.8 nm.

Table 6: Porosity-related characteristics

Substrates	Intrusion Vol. [ml/g]	Total pore area [m^2/g]	Ave. pore diameter [nm]	Porosity, [%]
Free Sheet	0.8162	15.970	204.4	41.27
Light Weight Coated	0.8248	16.249	203.0	59.77
Newsprint	0.8850	6.486	545.8	61.43
Semimatte Photo Paper	0.4370	36.886	47.4	36.66
Pearl Proof Paper	0.3962	43.880	36.1	37.25
Selected Proof Paper	0.2952	41.218	28.6	26.39

The pore size distribution of all tested substrates is shown in Figure 7. Newsprint has larger pore size at about 10µm. Free sheet coated paper and light weight coated paper have peaks of pore sizes between 0.1µm to 10µm, whereas proofing papers have two peaks groups of pore sizes between 0.1µm to 10µm and 1nm to 100nm, respectively.

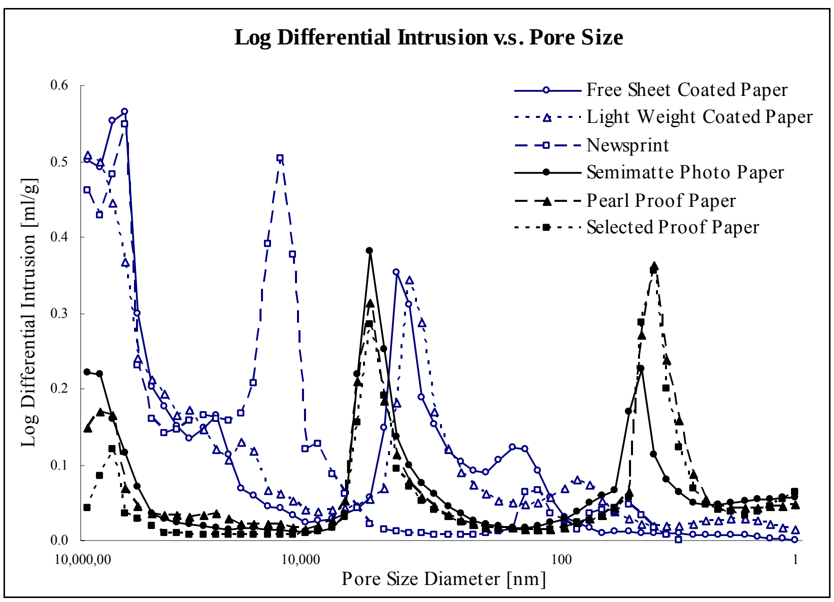


Figure 7: Pore size distribution from mercury porosimetry curves

Air Permeability Measurement

A related property, air permeability, is defined as the property of a paper that allows air to flow through it under a pressure difference across the sheet. The permeability of each substrate was calculated from the Parker Print Surf porosity value and its thickness using the following equation (Pal et al, 2006):

$$K = 0.048838 * Q * X \quad (3)$$

where K is the permeability in μm^2, Q is the flow rate of PPS 500 kPa in ml/min and X is the sheet thickness in m.

Air permeability measurement of tested substrates is shown in Table 7. It shows that newsprint has the highest air permeability value of 9.27E-04 μm^2 and largest standard deviation value. Comparing to printing papers, proofing papers tend to have smaller air permeability values.

Table 7: Air permeability measurement

Substrates	Air permeability [μm^2]	
	Mean	Std. Dev.
Free Sheet	11.06E-06	0.51E-06
Light Weight Coated	10.64E-06	0.98E-06
Newsprint	927.00E-06	103.91E-06
Semimatte Photo Paper	8.94E-06	2.21E-06
Pearl Proof Paper	0.36E-06	0.19E-06
Selected Proof Paper	1.24E-06	0.34E-06

Brightness Measurement

Brightness is the percent reflectance of blue light (as measured at a wavelength of 457nm), which is an indicator of how "bright" the paper is. Brightness has been expressed on a scale of 0 to 100. Most white papers are in the 60-90 brightness range (Biermann, 1996). A Brightimeter MICRO S-5 was employed to measure brightness % complied with TAPPI standard (C illuminant with 45°/0° geometry). Semimatte photo paper and selected proof paper containing optical whitener were measured automatically by build-in ultra violet cut-off filter. The measurement of brightness of tested papers is shown in Table 8.

Table 8: Brightness measurement

Substrates	TAPPI Brightness [%]	
	Mean	Std. Dev.
Free Sheet	79.34	0.16
Light Weight Coated	69.93	0.10
Newsprint	56.36	0.53
Semimatte Photo Paper	95.73	0.24
Pearl Proof Paper	89.26	0.13
Selected Proof Paper	92.98	0.28

The highest percent brightness was found in semimatte photo paper with 95.73%, followed by selected proof paper (92.98%), pearl proof paper (89.26%), free sheet coated paper (79.34%), and light weight coated paper (69.93%). Newsprint has the lowest percent brightness of 56.36%.

Whiteness Measurement

Whiteness is a color measurement which measures reflectance across all wavelengths in the visible light spectrum (380-780 nm) and provides a better idea about papers' color reproduction capability (Greenbaum, 2006). The Brightimeter MICRO S-5 was also used for whiteness measurements, offering both CIE whiteness (2004) and ASTM (E313-05) whiteness. Since the CIE whiteness can only be used in a limited region (3 > CIE tint > -3) and the tint value of newsprint was out of the range, ASTM whiteness was employed to data analysis in this study.

The ASTM Whiteness is given by

$$W_{ASTM} = 3.388Z - 3Y, \qquad (4)$$

where Y and Z are tristimuli measured with an illuminant C reference and a 2° observer. By construction, a perfect C/2 white point (Y = 100, Z = 118.06) has a W_{ASTM} of 100.

Whiteness measurements for tested paper are shown in Table 9 and Figure 8. Generally, proofing papers have higher whiteness values; whereas light weight coated paper and newsprint have relatively lower whiteness values. Figure 8 represents color spectra for all tested papers. As shown in Figure 8, proofing papers tend to have higher reflectance values in the blue region (420-470 nm), resulting in blue white appearance, most likely due to the presence of optical brighteners (Chovancova-Lovell and Fleming, 2006, 2007). Conversely, light weight coated paper and newsprint have higher light reflectance in the red region of the spectrum and thus look warm white.

Table 9: Whiteness measurement

Substrates	ASTM Whiteness	
	Mean	Std. Dev.
Free Sheet	77.02	0.43
Light Weight Coated	42.41	0.25
Newsprint	34.61	0.52
Semimatte Photo Paper	109.80	0.87
Pearl Proof Paper	88.98	0.22
Selected Proof Paper	99.00	0.80

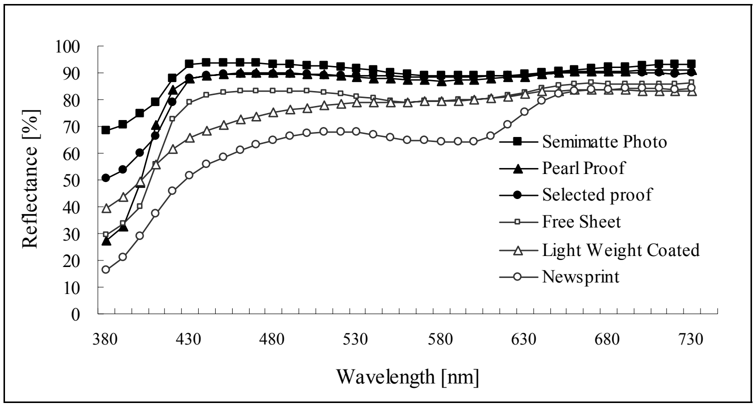


Figure 8: Color spectra of tested papers

Opacity Measurement

Opacity is the ability of paper to hide or mask a color or object in back of the sheet. The higher the opacity, the better the hiding power is and less show through (Biermann, 1996; Levlin & Soderhjelm, 1999). The opacity of a completely opaque paper is 100%. A BNL-2 opacimeter was employed to test opacity which is using TAPPI standard (opacity = $R_0 / R_{0.89}$). As shown in Table 10, the opacity readings for all tested papers are in the range of 90% to 97%, with the exception of light weight coated paper (with relatively low opacity of 81.98%).

Table 10: TAPPI opacity measurement

Substrates	TAPPI Opacity [%]	
	Mean	Std. Dev.
Free Sheet	90.79	0.55
Light Weight Coated	81.98	0.66
Newsprint	90.30	0.90
Semimatte Photo Paper	96.68	0.29
Pearl Proof Paper	94.55	0.53
Selected Proof Paper	90.05	0.50

Paper Gloss Measurement

Gloss is the attribute of paper surface that makes the images look shiny or lustrous. The gloss of a paper affects the color of a print because it affects the way light is reflected through the ink. Paper gloss at 75˚ was measured using a Novo-Gloss™ Glossmeter based on TAPPI standard. The measurement of paper gloss of tested papers is shown in Table 11. Pearl proof paper has highest paper gloss % of 63.13%, followed by free sheet coated paper (61.47%), selected proof paper (56.96%), light weight coated paper (49.67%), and semimatte photo paper (47.46%). Newsprint has the lowest paper gloss %, comparing to other substrates.

Table 11: Paper gloss measurement at 75° geometry

Substrates	Paper Gloss at 75° [%]	
	Mean	Std. Dev.
Free Sheet	61.47	2.52
Light Weight Coated	49.67	1.87
Newsprint	27.15	1.15
Semimatte Photo Paper	47.46	0.42
Pearl Proof Paper	63.13	1.46
Selected Proof Paper	56.96	1.01

4. Conclusions

The color gamut of the digital printers is affected by the substrate properties. The digital printer may be designed for a variety of substrates; however, the largest gamut and highest print quality of the device is obtained when the manufacturer recommended substrate being used. The device that is capable of reproducing a large gamut of colors on ideal substrates, may loose this advantage when using a different substrate.

The results show that the color gamut of proofing papers was wider than that of actual production printing papers which were printed via a Cerutti rotogravure web press. Proofing on the actual production printing papers with Epson Stylus Pro 4000 printer tends to yielded wider color gamut in yellow area but smaller color gamut in magenta and red regions. The press gamut is larger in the lower L^* value area where digital printer cannot reach because of low black density. For the Xerox Phaser 8550 printer, proofing whether on the proofing papers or printing substrates, digital printer tends to have wider color gamut in yellow and magenta areas. Xerox Phaser 8550 printer gamut is larger in the higher L^* value area, while the press gamut is larger in the lower L^* value area. The press gamut is larger in the lower L^* value area where digital printer cannot reach. There are some saturated colors that the press can achieve that the digital printer cannot, and vice versa. The Xerox Phaser 8550 printer color gamut for newsprint is larger than the press gamut.

Overall, proofing papers yielded larger color gamuts than actual production printing substrates in terms of gamut volume. Working with different ink technology, the gamut volume of Epson Stylus Pro 4000 printer is larger than that of Xerox Phaser 8550 printer for the proofing papers. The Epson Stylus Pro 4000 printer tends to have smaller gamut volume for the printing substrates. The Xerox Phaser 8550 printer, however, produces a larger gamut volume for the printing substrates, except for light weight coated paper.

The color gamut of the digital printers is affected by the substrate properties. It was found that paper with low roughness, high formation index, low porosity or air permeability, high brightness or whiteness, and high paper gloss properties exhibited a high gamut volume.

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