Printability of Different Epson Ink Jet Ink Sets

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Abstract

The development of high performance inkjet printers and inks is advancing rapidly. Presently, manufacturers seem to introduce their new technology inks to the market on an almost daily basis. Chemists in the ink laboratories are still fighting with the issue of combining the wide gamut of dye-based inks and the lightfast and weather resistance qualities of pigment-based inks into their new-age ink formulations. Simply, the evolution cannot be stopped!

Three different inkjet printers and inks were investigated in this work: the Epson Stylus® Pro 5000, using a dye-based ink set, the Epson Stylus® Pro 5500, employing Archival ink technology, and the Epson Stylus® Photo 2200, with 7-color UltraChrome™ inks. A number of different commercial and experimental substrates were sampled. Printability tests were carried out to test and evaluate ink/printer/substrate interactions. Particle size analyses of the three ink types were investigated. Color gamuts for each of the different printer/ink/substrate sets were compared. In addition, the accuracy of each printer's color profile was investigated. The results of the profile accuracy measurements were expressed in terms of CIE $L^*a^*b^*$ coordinates and Root Mean Square (RMS) ΔE. In addition, the operating costs of ink/media sets were taken into consideration.

Introduction

Undoubtedly, we are now seeing wide development of novel technologies in manufacturing inks and substrates, and due to that, an expansion of inkjet printing technology into desktop, outdoor and industrial applications. [1,2]

Epson has recently introduced two types of pigment-based inks. They combine the advantages of both dye and pigment based inks in their formulations. Both their Archival and UltraChrome™ ink systems represent new ink solution~~s~~, where each pigment particle is encapsulated in a resin. This technology offers many advantages over conventional pigment and dye based inks. The primary advantages being those of uniform particle shape and particle size, greater color gamut, advanced optical density, exceptional gloss for photo prints, enhanced lightfastness and support for a wider range of media.

Pigment based inks tend to satisfy the requirements of most ink jet printing demands, but the suitable combination of ink and substrate is still crucial. Inkjet inks require a fine particle size, due to possible clogging of the printing head. For low viscosity inks there is a tendency of particle migration with time.[3] Pigment based inks behave differently than dye-based inks. The spreading behavior of these inks is determined by the hydrodynamic properties such as the Weber or Reynolds's number. On the other hand, in pigment-based inks, after initial spreading, the pigment particles coagulate on the surface of the microporous layer~~,~~ creating a filter cake that limits the penetration of the carrier liquid. This results in longer absorption times and recessed dots that stay on the top of the substrate layer, and affect all the other printability properties. [4]

Also, the precision of color reproduction depends on the image processing, e.g. color separation, rendering intent~~s~~, and on the stability of the printing process, which usually is carried out with the help of an ICC profile and Color Management Modules.[5-9] In order to understand the whole process, the influence of paper properties on color reproduction has to be taken into consideration. The grade or type of the substrate used will definitely affect the results of the profile calculations and therefore the printing gamut.[10]

Procedures and Results

All the printers (Epson Photo 2200, Epson Stylus PRO 5000, Epson Stylus PRO 5500) were profiled as CMYK devices on the six selected substrates (Epson Archival Matte, Epson Premium Luster Photo, Epson Premium Glossy Photo, Kodak Glossy, Kodak Satin Paper and experimental substrates with a special inkjet coating applied[11-13]), using a GretagMacbeth SpectroScanT spectrophotometer, GretagMacbeth ProfileMaker 4.1.5 and the ECI2002 Random Layout CMYK Target.[14] Sample test prints were produced from Adobe InDesign. In "Color Settings" the CMYK working space was set to the appropriate .ICC profile. The prints were made with color management set to source space as proof and the applicable CMYK profile for the print, with the intent set to Absolute Colorimetric for the sample output. (The "proof space" is the only management that allows the intent to be manually set.) Therefore, all output was set for an absolute colorimetric intent.

Density Tests

The samples for all substrates were measured with an XRite 530 SpectroDensitometer. Paper density, Solid density and

Dot Area were measured for each sample. The dot area as measured and calculated by the device includes both mechanical and optical gain. Also listed in the results is the difference "Dot Gain" assuming the actual dot size to be a true 20%.

ICC Profile Test

Profile accuracy tests were carried out using the following steps. The values of the ColorChecker® target in Photoshop with the profile applied for each paper sample were checked first. This was accomplished by selecting a large portion of each patch and then recording each of the $L^*a^*b^*$ values from the "Histogram" portion of the "Info" palette. The Mean values obtained from the histogram were converted to actual $L^*a^*b^*$ values. Using the GretagMacbeth SpectroScanT, $L^*a^*b^*$ measurements were made for each of the sample patches of the ColorChecker® target for all of the substrates and for each of the sample printers. Employing the formula for color difference "ΔE"[15],

$$\Delta E = \sqrt{\left(L_1^* - L_2^*\right)^2 + \left(a_1^* - a_2^*\right)^2 + \left(b_1^* - b_2^*\right)^2} \qquad (1)$$

the original $L^*a^*b^*$ values of the ColorChecker® target (Target values) were compared with the values from Photoshop with the profile applied (Profiled values). These values were also compared with the actual values measured from the printed ColorChecker® portion of the verification samples produced from InDesign, and finally the original values were compared with the values measured from the ColorChecker® Target (Test values). The resultant values for Delta E are listed in Table 1.

IT8/7-3 Subset Test

The subset part of the IT8/7-3 chart was included in the verification page layout. The $L^*a^*b^*$ values of the patches were measured with the GretagMacbeth SpectroScanT and compared with the original data of IT8/7-3 chart in order to investigate the quality of the profiles made for each scanner/ printer/paper set. Resulting RMS ΔE's are shown in Table 1.

Color Gamut Comparison

Using CHROMiX ColorThink 2.1.2, the profile gamuts for each of the printers were compared in this order: Epson Photo 2200, Epson Stylus PRO 5000, Epson Stylus PRO 5500, and then we compared the similar substrates, Glossy and Matte/Satin, from each printer to each other. The results were combined and are shown on the gamut plots (Fig. 1-4).

Table 1. RMS ΔE Results.

	RMS ΔE			
EPSON Paper	**Target**	**Profile**	**Target**	**IT8/7**
Photo 2200 Archival Matte	2.42	2.11	2.54	7.55
Photo 2200 Luster Photo	1.48	2.80	2.87	4.39
Photo 2200 Glossy Photo	1.33	1.65	2.02	3.79
PRO 5000 Archival Matte	1.10	1.80	2.02	7.38
PRO 5000 Luster Photo	0.91	2.09	2.30	3.27
PRO 5000 Glossy Photo	2.04	2.55	3.59	4.86
PRO 5500 Archival Matte	4.50	1.37	4.55	12.86
PRO 5500 Luster Photo	1.01	1.85	1.92	8.33
PRO 5500 Glossy Photo	1.38	1.89	2.17	9.66
KODAK Paper	**Target vs. Profile**	**Profile vs. Test**	**Target vs. Test**	**IT8/7 Test**
Photo 2200 Satin	1.52	1.56	1.99	6.80
Photo 2200 Glossy Photo	1.26	1.93	2.16	6.67
PRO 5000 Satin	1.24	5.00	5.17	5.43
PRO 5000 Glossy Photo	1.18	5.76	5.87	6.18
PRO 5500 Satin	4.78	2.30	5.77	13.06
PRO 5500 Glossy Photo	3.33	2.05	4.28	11.31

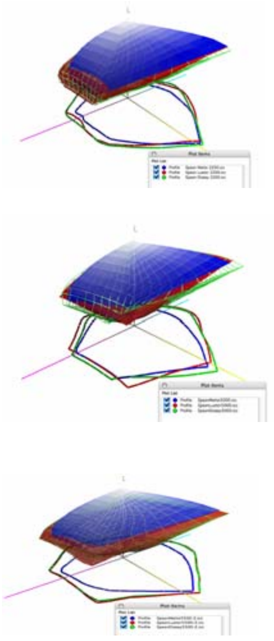

Fig. 1. Gamut Plots for Epson Papers.

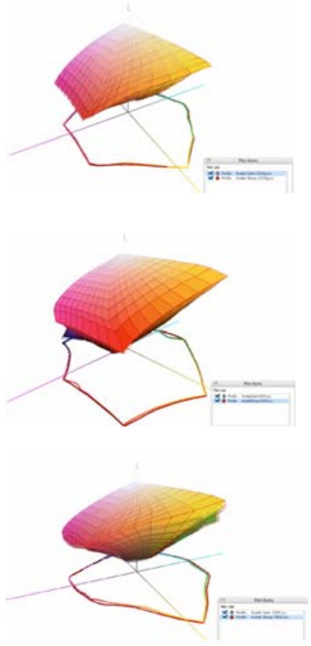

Fig. 2. Gamut Plots for Kodak Papers.

We also compare gamuts for experimental papers.[11-13] These were formulated with a 50:50 ratio of alumina to baumite nanopigments [11], at a pigment-to-binder ratio of 7:1

and final solids of 30 ±1%. The coatings were applied to a 75 g/m^2 commercial base paper using a Cylindrical Laboratory blade coater at a speed of 2000 fpm. Coating weights between 6 and 12 g/m^2 were obtained. Some of the 12 g/m^2 samples were printed on the three printers with the i1 CMYK Target 1.1[16], before calendering. The remaining coated samples were calendered on one side, through 3 nips at 123 kN/m and 60 °C. Three 10 g/m^2 calendered samples were printed with the i1 chart on the three printers. ICC profiles for the printers with the noncalendered and calendered papers were calculated using the printed i1 chart, using GretagMacbeth ProfileMaker.

The profile gamut plots for the experimental papers are given in Figures 5-7. Figure 5 shows the effect of calendering on color gamut, while Figures 6 and 7 compare the noncalendered and calendered papers with the Epson glossy and matte, respectively on the three printers.

Fading Test

The patches of the ECI 2002 Random Layout CMYK Target were measured with the GretagMacbeth Spectro-ScanT before they were put into the fade meter. They were submitted to 129,600 kJ/m^2 of energy over 48 hours and measured again. This represents about 6 months of daylight exposure in Florida [16].

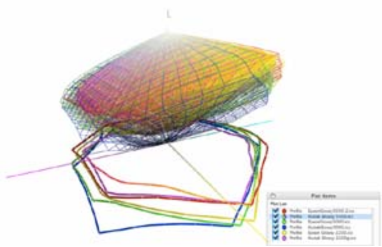

Figure 3. Gamut Plot of Glossy Substrates from All Printers.

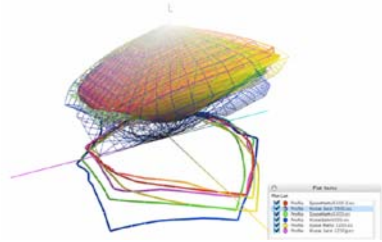

Figure 4. Gamut Plot of Matte/Satin Substrates from all Printers.

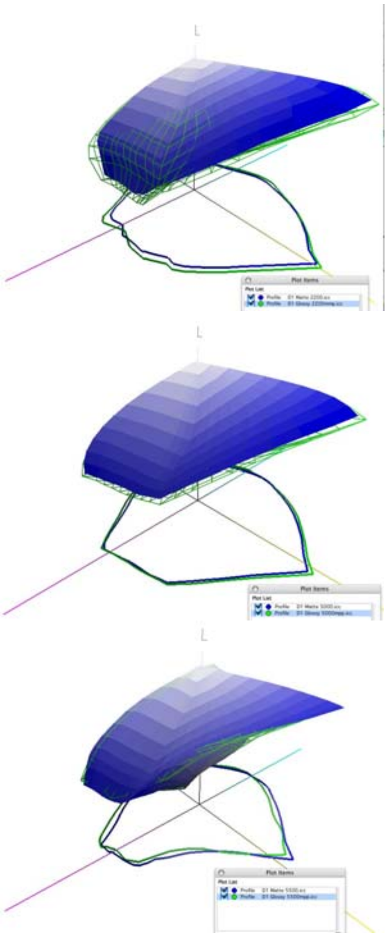

Figure 5 Gamut Plots for experimental papers.

The GretagMacbeth MeasureTool 5.0.0 software was used to compare the spectra of the substrates before and after the fading test. The spectrum for Epson Archival Matte substrate, claming the best archival properties, and for Kodak Satin substrate are shown in Figures 8 and 9.

In addition, the L*a*b* values of the substrates before and after the tests were taken from the data file and ΔE calculation was performed to obtain the range of color difference between them. These are shown in Table 2.

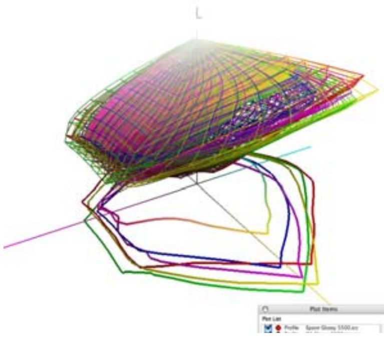

Figure 6. Gamut comparison for experimental calendered paper and Epson Glossy paper for all

The spectra and the L*a*b* values suggest that the contribution of optical brighteners, added to improve the perceived whiteness of the paper, has been neutralized for the Archival Matte paper and greatly diminished for the Kodak Satin papers. Optical Brightening Agents (OBA) are fluorescent materials that absorb in the ultraviolet and emit in the blue (16,17). This is the source for the blue peak in the spectra and the negative values of b* before the fading test. This means that, regardless of the permanence of the printed dye or pigmented ink, there will always be some shift in the perceive color of printed images.

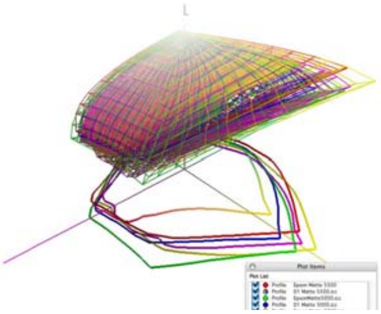

Figure 7. Gamut comparison for experimental non calendered paper and Epson Matte paper for all printers.

In order to evaluate these effects, we compare the colorimetric values and color gamuts for different inks on these papers before and after the fading tests. The results for the Archival Matte for the Epson 2200 and 5000 and the Kodak Satin for the Epson 5500 are given in Table 3.

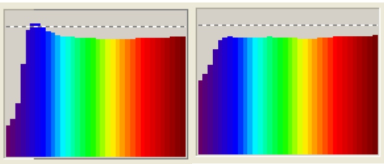

Figure 8. Spectrum of Epson Archival Matte Substrate Before and After Fading Tests.

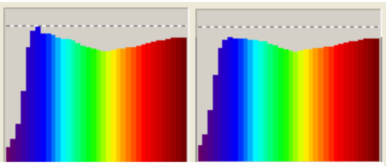

Figure 9. Spectrum of Kodak Satin Substrate Before and After Fading Tests.

Table 2. L*a*b* Values and ΔE of the Epson Archival Matte and Kodak Satin Substrates before and after the fading test.

Paper		L*	a*	b*	ΔE
Epson Archival Matte Paper	Before	96.1	0.8	-4.3	**4.34**
	After	95.8	-0.4	-0.1	
Kodak Satin Paper	Before	93.3	0.7	-6.3	**2.49**
	After	93.4	-0.1	-3.9	

Table 3. Average and RMS ΔE values before and after fading test for different printers and papers.

Paper	Printer	Average ΔE	RMS ΔE
Archival Matte	Epson Stylus PRO 5000	10.62	11.34
Archival Matte	Epson Stylus PRO 2200	2.20	2.74
Kodak Satin	Epson Stylus PRO 5500	2.90	3.35

Table 3 does show that the pigmented inks change colors much less than the dye inks as expected. However, values ~3 for the pigmented inks are larger than expected for inks rated at more than 75 years [18,19]! Examination of the data shows that there is a systematic shift toward yellow and green. The Epson 2200 shows an average Δb* of 1.57, while the Epson 5500 shows an average Δb* of 1.89. Thus, for the pigmented inks, most of the average ΔE results from the systematic Δb* shift, reflecting the drop in the OBA contribution. The Epson 5000 shows an average Δb* of only .77, but the average ΔL* is 6.96. Therefore, that ΔE is mostly due to actual ink fading.

Figure 10 shows the gamut plots before and after the fading test. Note that the Epson 5000 shows a significant decrease in color gamut, The printers with the pigmented inks, the Epson 2200 and 5000 show the aforementioned shift towards yellow, but little decrease in gamut.

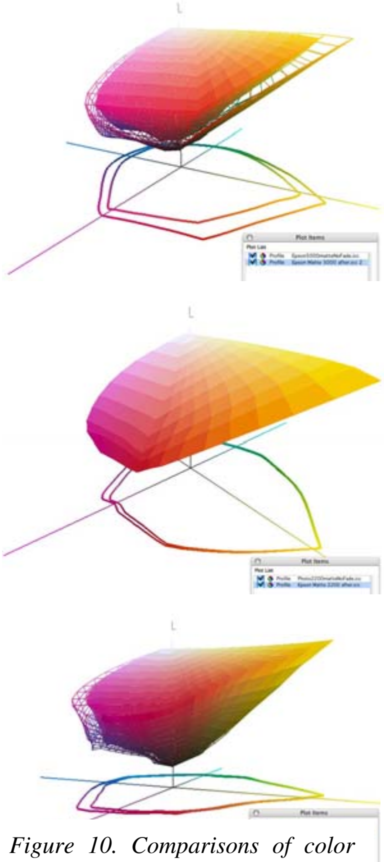

Figure 10. Comparisons of color gamuts before and after fading test for Epson 5000 (top), Epson 2200 (middle) and 5500 (bottom).

Particle Size Measurements

A NICOMP 370 Submicron Particle Sizer was used to measure the particle size of all the ink sets. As expected, no particles were detected in the dye-based ink set for the Stylus PRO 5000 printer. The measured particle size of all pigmented inks are found in Table 3.

Table 5. Particle Size of All Ink sets.

Particle Size	C (nm)	M (nm)	Y (nm)	K (nm)
Epson Stylus PRO 5500	128	157.5	58	82
Epson Stylus PRO 2200	76.0	114	75	55
Epson Stylus PRO 5000	Dye	Dye	Dye	Dye

Price List

All information about costs of the products used in this work was obtained from the manufacturer's websites or phone. Price comparison and operating cost of ink/media sets are listed in Table 4.

Table 6. Price List of .the Printers, Ink Cartridges and Raster Image Processor (RIP) Used in Experiment.

Printers and Inks	**Price***
Epson Stylus PRO 5000 w/RIP	**$3,000**
Ink cartridge (each)	**$65**
Epson Stylus PRO 5500 w/RIP	**$3,500**
Ink cartridge (each)	**$65**
Epson Stylus Photo 2200	**$700**
Ink cartridge* (each)	**$65**

*equivalent in volume

Paper	**Price***
Epson Premium Glossy Photo (50 pcs)	**$35**
unit price	**$0.70**
Epson Premium Luster Photo (20 pcs)	**$15**
unit price	**$0.75**
Epson Archival Matte (50 pcs)	**$16**
unit price	**$0.32**
Kodak Glossy (40 pcs)	**$30**
unit price	**$0.75**
Kodak Satin (40 pcs)	**$30**
unit price	**$0.75**

RIP	**Price***
EFI Designer Edition XL software RIP	**$750.00**

* approximate price up to purchase date

Other Properties of Printer/ Substrate Combinations

Other properties of the Printer and substrate combinations are given in a companion paper[19]. In particular, the paper roughness by Parker Print Surf[20], profilometer[21] and Atomic Force Microscopy[22]. In addition, ink and paper gloss were measured for both 60 and 75°[13].

Discussion

The procedures used with the densitometer and the measurements obtained by that method produced comparative values for the 20% dot area on all of the samples, and all measurements were of comparative values for all of the papers and inks. The matte samples from all printers did represent a lower density than those of the luster and glossy samples. The dot gain seemed relatively consistent for all colors on all samples.

The comparison of the difference in ΔE values for the original $L^*a^*b^*$ ColorChecker® target to those of the values calculated in Photoshop indicate small dissimilarities in almost all cases. The ΔE values for most of the patches on all substrates and from all printers were found to be generally less than two (2). Exceptions include the dark patches when printed on the Matte papers and when printed from the Photo 2200 and PRO 5500 using pigment based inks. In the case of the pigment based ink printers (Epson 2200 and Epson 5500) the average and RMS ΔE were always higher for the Matte substrates than for the Luster, Satin and Glossy substrates.

The ΔE values for the comparison of the patches calculated in Photoshop to those measured with the SpectroScanT show similar values to the differences between the original values and the values from Photoshop in the case of all Epson papers. The only exception is the Epson Stylus PRO 5000 in combination with Kodak substrates.

Comparisons of the measured samples in most cases very closely approximate the values of the original ColorChecker® reference values, with the largest variances indicated on the Glossy papers printed from the PRO 5000 and the Matte from the PRO 5500. Matte paper printed from the PRO 5500 produced the largest variances of all the samples.

In comparing the profile gamuts it was noted in all cases that the Matte paper profile represented the smallest gamut whereas the Luster and Glossy papers were generally similar and included the complete Matte gamut. Comparing the printers to each other on the same substrate the Photo 2200 generally included a similar size gamut to that of the PRO 5000 printer and dye based inks but the PRO 5500 represented the smallest color gamut. It could be seen that the Photo 2200 with its pigment based inks is able to provide a color range that very closely matches that of the dye based prints from the PRO 5000.

The smaller gamut produced by the PRO 5500 printer may have something to do with the older technology and/or the advertised better archival properties of the ink set used by that printer. The fact that the pigment based inks used in the Photo 2200 printer closely match those of the dye based inks of the PRO 5000 is noteworthy, but it can be expected that the archival properties as advertised for this ink set may not be as good as those of the PRO 5500. It should also be noted that the increased archival properties of the Matte paper in combination with archival pigment based inks produce the smallest color gamut of the samples analyzed.

Taking into the consideration the Kodak paper, there is no difference in gamut size between Glossy and Satin substrate. In addition, Epson vs. Kodak paper gamuts did not show any significant discrepancies in the terms of color gamut size. It is seen from Figurers 3 and 4 that the widest gamut was obtained when printed from the Epson Stylus PRO 5000 dye based inkjet printer followed by Epson Photo 2200 and Epson Stylus PRO 5500, both pigment based inkjet printers.

After the printouts were submitted to the fading test it could be seen that the gamuts decreased. The Epson 5000 showed a significant decrease, while the 2200 and 5500 showed small changes. In the case of the Epson Archival Matte and as well the Kodak Satin substrate, it was found that even without any change in ink composition the color performance will change because of the loss of brightener effect. This led to a systematic shift toward the yellow, as shown in Figure 10. This deviation was not seen when inspecting the other substrates.

The particle size of the pigment based inks were found to be in the range <170 nm, most of them bellow 100 nm, showing smaller particle sizes for the PRO 2200 ink set than for the Photo 5500 ink set. The Particle Sizer's light detector was not able to distinguish any intensity in the case of the PRO 5000 ink set, which is consistent with the dye based ink system of the printer. The color gamut decreases with particle size, with the smallest particle size , the Epson 5000 dye, having the largest gamut, while the largest particle size, the Epson 5500, gives the smallest gamut. However, the dye based ink in the 5000 showed significant fading from a simulated 6 month exposure.

The price/performance of the newest version Epson printer and the ink set tested is very impressive. We all continue to marvel at how far the price and performance of ink jet printers have come.

Conclusion

Different inkjet printers and their corresponding ink sets were studied in terms of printability tests, ink/printer/substrate interactions, particle size analyses, color gamut~~s~~ comparisons, the accuracy of printer's color profile, fading tests and operating costs of ink/media sets. It can be definitely said that the new technology of the manufacturing the inks with pigment particles encapsulated in specific resins is able to approach the properties of the dye based inks, especially in the term of gamut width. The particle size of the pigment in these inks is small enough to provide the color range that could match that of the dye based inks and also reach the gamut of digital silver halide photo on conventional photo paper.[2] Also, it has to be mentioned that the increased archival properties of the Matte paper in combination with archival pigment based inks reflect in the smaller color gamut than the gamut of Glossy paper. The pigment based inks show much better lightfastness than the dye based inks, but for some substrates there is a drift towards the yellow as optical brighteners lose their effect.

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Biographies

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