The effect of colorants in proofing systems in comparison to standard four color process inks

Martin Habekost*

Keywords: Color, Colorants, Gamut, Metamerism, Proofing

Abstract: This study concerns the evaluation of the colorants of inkjet and laser proofing systems and their comparison to printed offset process colors.

Various types of proofing systems are being used today. In this study only inkjet ink and laser toner based systems were evaluated. These proofing systems use different colorants then pigment based offset printing inks. Due to the different chemical composition of inkjet inks and laser toners in comparison to the pigments used for printing on press, color differences are to be expected between printed sheet and proof.

The study intends to see how big the differences between 4 color process inks and randomly selected proofing systems are using color measurements with the CMC-tolerancing method. The prints will also be used to determine the obtainable color gamut of the evaluated systems. The gamut evaluation will also show if either system can reproduce colors that the other one can't.

Differences between the spectral curves of printing inks and the dyes can lead to metameric effects when proof and print are viewed under different lighting conditions (press-side and office lights).

The result of this study is that the cyan colorants showed the smallest color difference, while the magenta colorants showed the largest difference in comparison to the set standard. The smallest metameric index was observed with the cyan colorants. The yellow colorants gave the largest metameric index in this study.

*Ryerson University, School of Graphic Communications Management

Introduction

In the past ink manufacturers have been asked numerous times to change their four color process inks to match the colors of their customers newly purchased proofing system. These printing companies printed out the four color process colors plus the overprints from their proofing system and sent them as color standards to their ink manufacturing company so that they could be matched.

Matching the colors of the proofing system resulted often in awkward pigment combinations. Magenta's had to be tinted with yellow, orange or cyan; cyan's had to be tinted with greens or violet and sometimes yellow's had to be tinted with orange so they would match the colors on the supplied proof. Another factor was the stock the proof was provided on. Quite often it was a high gloss material that was different from the actual stock.

After the colors had been matched and manufactured they were put on press and matched the proof, but other standard print characteristics were compromised. In the long run the printing company switched back to their traditional four color process inks so they didn't have to compromise on the overall print quality.

This shows that the underlying idea of matching the offset printing ink colors to the colors of the proofing system was a good one but some ink characteristics like trapping had been negatively influenced.

Another aspect that was overlooked was, that the manufacturer of the proofing system might change the colorants in the future to get closer to the colors of traditional four color process printing inks. This would mean that the four color process inks need to be changed again and it might be difficult to match a previous printed job, if it had been printed with the special set of four color process inks.

Another aspect that would be a disadvantage to the printers' business is, that with their special process colors they could not be part of a very large press run that would be spread between various printing companies, because they could not match the colors of the printed sheets of the other printing companies. Instead of matching process colors to proofer inks we may use color management systems (ICC profiling or proprietary closed looped) to achieve press to proof match.

Proofing has come a long way since the Chromalin proofs. Chromalin proofs have dominated the proofing market in the 80's and were succeeded by Iris proofs in the 90's. The newer competitors in this market are now companies like Canon, Epson and Hewlett-Packard.

Since then the use of inkjet based devices and proofing solutions has exploded and has led to the development of 6 – 8 color based inkjet-proofing systems. In fact inkjet proofing has gone mainstream (Felici, 2004). Multicolor inkjet proofing solutions were introduced to the market to allow for better reproduction of subtle color differences, mainly highlights. The color gamut of 6-color inkjet systems was not increased in comparison to a four color based system. Light cyan and light magenta are used to improve the apparent resolution. Light inks are used for highlights (Livens, 2002). The use and feasibility of inkjet proofing systems was one research activity (Shyu, 1999) and also the use of color management for consistent inkjet proofing quality has been investigated (Livens, 2002).

Nowadays color management is a part of the proofing solution to ensure consistent quality from proof to proof. The use of ICC profiles together with color management brings inkjet printers even closer to the press sheet (IPA 2005).

Experimental

The previous statement has a very interesting point. In order to see how close today's proofing solutions are to a press sheet three inkjet ink and the three laser toner based systems were randomly chosen for evaluation. The printed samples had a GATF Test form or process color patches printed on them, so "clean" proofing colors could be analyzed. A magnifying glass was used to ensure that no additional colors were printed in the area where a single color should be present, i.e. a solid yellow with 5% cyan screen.

An in-house printed GATF test form printed at target densities for a coated sheet was set as standard for color, hue angle and color gamut.

Color measurements were done with an X-Rite 530 instrument in combination with X-Rite's QA 2000 and Toolcrib software. All measurements were taken three times and then averaged.

The computation of the color gamut was done by a matrix calculation based on the hexagonal tightest sphere packing principal around a specific color to estimate the number of possible color combination based on L*a*b* color measurements (Paul, 1999). The color measurements of all four process colors plus the three overprint colors and the paper white are needed for the color gamut determination.

The metameric index has been calculated according to DIN 6172 with D50/10° as standard illuminant/observer and F2/10° as secondary illuminant/observer to simulate possible color differences under controlled press light viewing conditions and office lights. The D50 illuminant rep-

resents the 5000 Kelvin press light viewing conditions. The press side viewing conditions are considered standard viewing conditions.
In this study the following three inkjet colorants and three laser toner based colorants were evaluated but will not be identified:

- HP Designjet 130
- Kodak Veris
- Pantone ColorVantage Inks for Epson printers
- Canon C 2620
- Canon CLC 1180
- HP Laserjet 5500.

Results

Color differences for Yellow

Color differences were measured with an X-Rite 530 instrument and X-Rite's QA2000 quality control software. The color difference is expressed as $DE_{CMC\ 2:1}$ under D50/10°.
Color measurements from an in-house printed press sheet at target densities with a GATF-Testform on a #1 coated sheet were set as the standard colors. For visualization it is benefical to have a look at the spectral curves of all the yellow colorants involved.

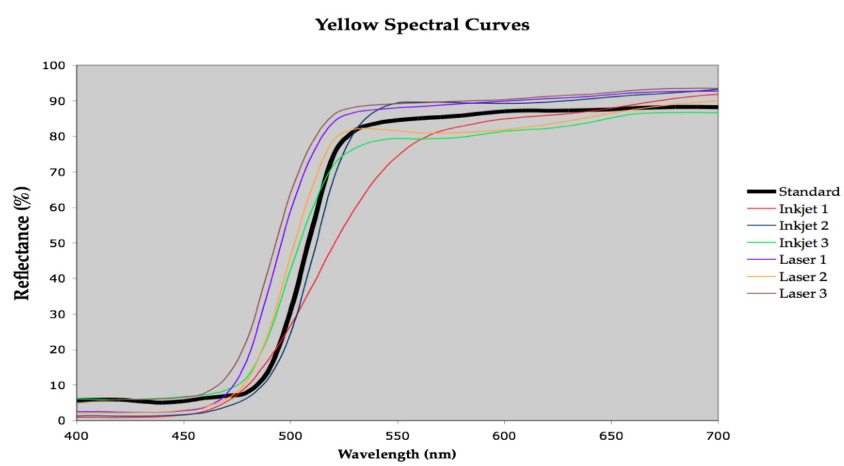

Figure 1 Spectral curves for all yellow colors

These curves vary a lot, especially in the area between 460 to 500 nm. This area determines how much blue/green will be in the spectrum of each color. Most colorants have more blue/green components in their reflectance curve then the standard yellow. Already from these curves it can be seen that there will be a difference between the standard and the all samples. How big this difference will be can be expressed in the DE and the difference in hue angle between the standard and the samples.

Yellow	**$DE_{CMC\ 2:1}$**	**Density (T), Target: 1.00 ± 0.10**
Standard	N/A	1.03
Inkjet 1	4.26	1.14
Inkjet 2	3.99	1.19
Inkjet 3	3.8	0.90
Laser 1	4.14	0.84
Laser 2	3.36	0.96
Laser 3	5.62	0.74

Table 1: Colour differences between the standard pressheet and obtained proofing samples

These DE-numbers show that there is quite a measurable difference between the standard and the samples, although it is not uncommon to measure a DE of up to 3 caused by density variations during a press run (Fraser 2003). It should be noted that there is no technical requirement for the press colorant to match the proof colorant, per se, because this can be achieved using color management, nevertheless this analysis quantifies how "different" the colorants are.

The only outstanding difference is between the press sheet and the Laser 3 printout. This might also have to do with the density that the yellow was printed at. It differs a lot from the standard printed density.

If the print from Laser 3 would be at a comparable density level the color difference would be smaller. Although it has been stated that comparing densities across processes makes no sense (Livens, 2002) it still gives an indication to why there is a much bigger color difference.

The L*a*b*-plots generated in QA2000 together with the hue angle of the colors were examined to see if there is a trend in the color difference between the standard and the colorants used in the various proofing solutions. The proofing colors were mostly more green then the standard. Only Inkjet 1 and 2 are more yellow then the standard. This can be seen in the following figure.

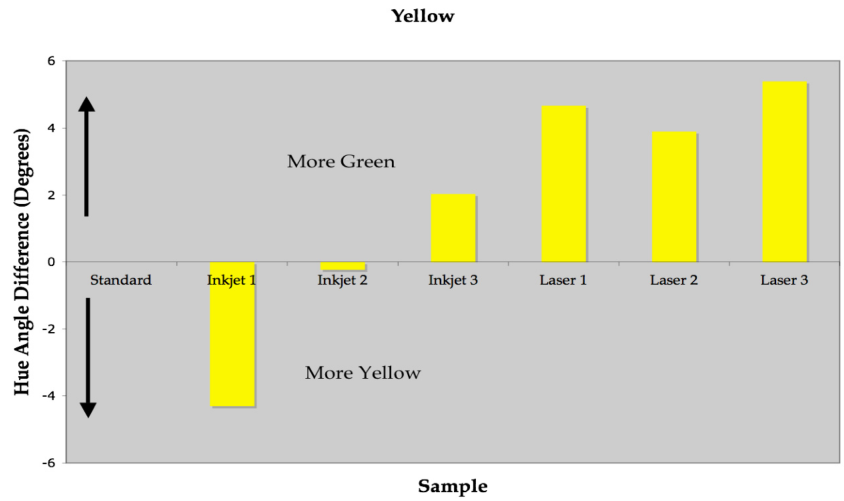

Figure 2 Hue Angle comparison between all yellow samples and standard

The differences in the spectral curves and also the hue angles make it understandable that for example a solid yellow printed with an offset process yellow will look different if it would be printed with a colorant from a proofing system. This difference can be minimized through the use of color management were additional colors are printed simultaneously with the yellow color to give the human observer the color impression of a press sheet yellow. These additional colors will not appear on the yellow printing plate, but are solely printed on the proof, so the color impression is as close as it can be to the press sheet.

Color differences for Magenta

In the past magenta and cyan have been difficult colors in the proofing solutions since the offset printing ink is made from pigment and the proofing ink is made from dyes or toner. Even if the inkjet ink is made from pigment it is probably not the same pigment as the one used in offset printing inks. Since magenta and cyan can often be the dominating colors in a printed product it is clearly understandable that a significant color difference between magenta printing ink and the magenta used in the proofing solution will lead to a visible difference.

A first glance at these differences can be taken by looking at the spectral curves of the standard magenta and the magenta curve from the evaluated samples.

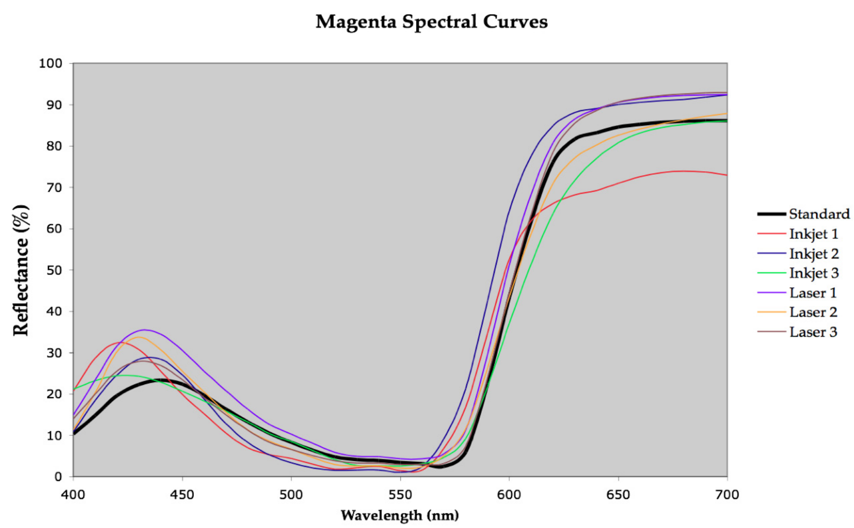

Figure 3 Spectral curves of all Magenta Colors

The main difference is visible in the reflectance values that are between 420 and 450 nm. This is the blue area of the visible spectrum. A hue difference towards to the blue can be expected. All involved proofing colors have higher reflectance values in this area and the maximum of this reflectance is at a different wavelength in comparison to the standard. There are also various amounts of yellow and red reflected back from 600 to 700 nm. This will also result in color differences between the standard and the evaluated samples. The numerical differences between the standard and samples are shown in the table below.

Magenta	**$DE_{CMC\ 2:1}$**	**Density (T), Target: 1.50 ± 0.10**
Standard	N/A	1.44
Inkjet 1	6.83	1.74
Inkjet 2	3.61	1.52
Inkjet 3	4.04	1.38
Laser 1	6.35	1.22
Laser 2	5.89	1.47
Laser 3	3.25	1.38

Table 2: Color differences between the standard press sheet and obtained proofing samples

The proof made with Laser 3 is the closest in color to the set standard. Inkjet 1 shows the biggest color difference of all evaluated magenta's but it is also printed at a much higher density than all other colors. Printed at target density the color difference would probably be less.

Another aspect that needs to be evaluated is the hue angle difference between all colors.

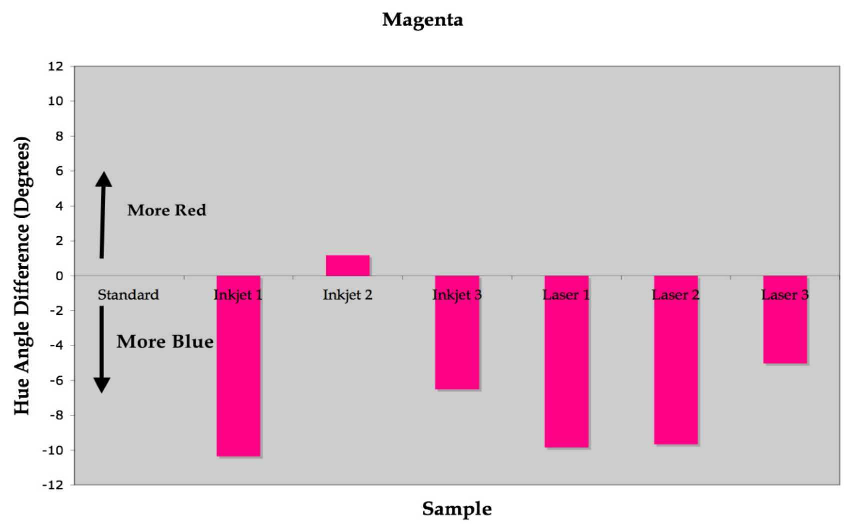

Figure 4 Hue angle comparison between all magenta samples and standard

The colorants from Inkjet 1, Laser 1 and 2 show bigger hue angle differences. Most evaluated magentas are bluer in shade then the standard. This can be critical when colors like skin tones and tan colors are printed on press and the press sheet is then compared to the proof. Only the magenta from Inkjet 2 is redder in shade then the standard. This magenta shows the smallest hue angle difference compared to the standard. The smaller the difference is between process ink and proofing colorant the lesser work color management has to do to correct the shade of the Magenta how it will be perceived by the human eye.

<u>Color differences for Cyan</u>

Magenta and cyan can quite often be the dominant colors in CMYK printing. Therefore color differences of these colors between press run and proof should ideally be at a minimum level. A first impression of the color differences between the standard cyan and the evaluated samples is given by looking at the reflectance curves. Minimal color differences would be observed, if the curves would be very close to each other.

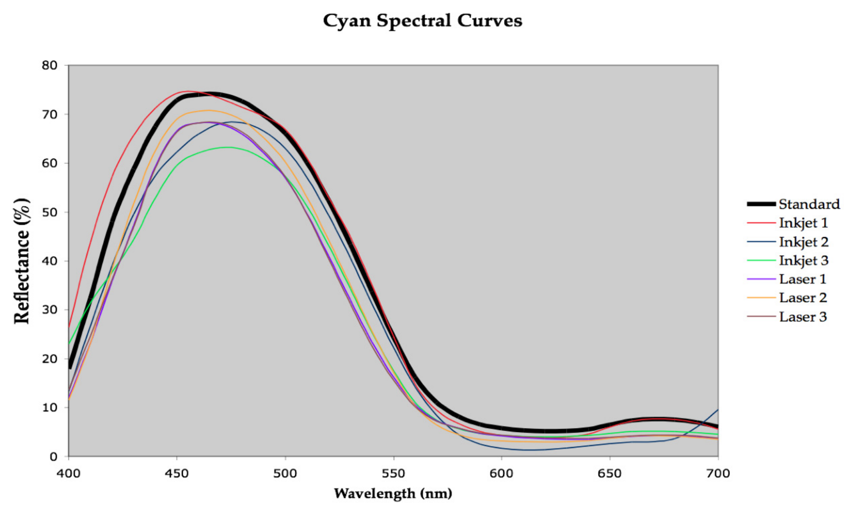

Figure 5 Spectral curves of all Cyan colors

All evaluated Cyan colors have lower reflectance maxima then the standard. The maximum reflectance lies between 450 and 480 nm.
There is also a difference in the initial spectral components of the Cyan colors. Together with the varying reflectance maxima different areas of the blue/cyan part of the visible spectrum are part of each spectral curve. How this translates into color difference numbers is shown in table 3.

Cyan	**$DE_{CMC\ 2:1}$**	**Density (T), Target: 1.40 ± 0.10**
Standard	N/A	1.48
Inkjet 1	1.51	1.58
Inkjet 2	2.16	1.43
Inkjet 3	1.99	1.38
Laser 1	2.79	1.38
Laser 2	1.00	1.51
Laser 3	3.12	1.38

Table 3: Colour differences between the standard pressheet and obtained proofing samples

These color difference numbers are actually quite low and can often occur as normal variances during a press run. Low color difference numbers allow better color reproduction between press sheet and proof and translate also into less color management that needs to be applied to the proof to adjust the observed cyan color.

The next evaluation point is the hue angle difference between the standard cyan and the evaluated cyan colors. These differences are shown in figure 6.

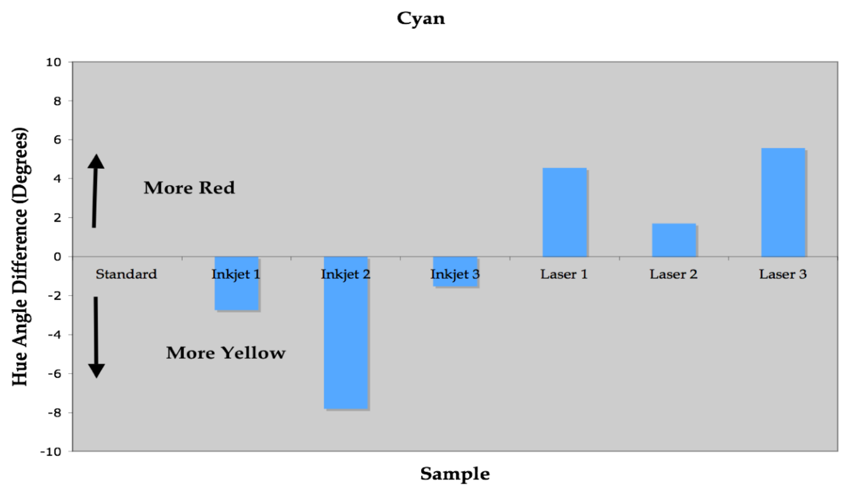

Figure 6 Hue Angle comparison between all cyan samples and standard

This hue angle comparison is quite interesting, since the inkjet based systems have a yellow hue difference in comparison to the standard and the laser toner based systems show a hue shift to the redder side of cyan. The cyan from Inkjet 3 and Laser 2 have the smallest hue angle difference, while Inkjet 2 shows the biggest. The smaller the hue angle difference is between standard and sample the more accurate the cyan color of the proof is to the offset printing ink. Smaller hue angle differences lead also to smaller color corrections on the proof to shift the hue more towards the standard color.

Color differences for Black

The evaluation of black color differences was not conclusive since some inkjet-based systems used so-called Photo- or Intense Black. These intense blacks are sometimes printed at higher densities then a four color process black. The following figure shows the different spectral curves for all black colors.

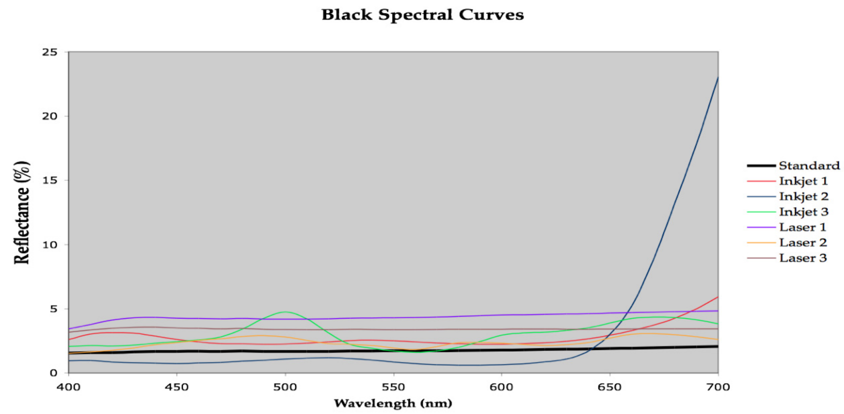

Figure 7 Spectral curves for all Black colors

These graphs show quite clearly how different the colorants from either inkjet ink or laser toner proofing solution are in comparison the black ink from the standard press sheet. The numerical values of these differences are given in table 4.

Black	**$DE_{CMC\ 2:1}$**	**Density (T), Target: 1.70 ± 0.10**
Standard	N/A	1.75
Inkjet 1	4.74	1.61
Inkjet 2	7.52	2.02
Inkjet 3	4.54	1.60
Laser 1	8.49	1.42
Laser 2	5.35	1.59
Laser 3	7.38	1.47

Table 4: Color differences between the standard press sheet and obtained proofing samples

If differences like this occur between offset printing ink and proofing solution colorant color management can and has to minimize these differences.

Color Gamut

For the color gamut evaluation the in-house printed press sheet was set as standard. The matrix-based calculation needs the L*a*b*-values of the four process colors (CMYK) plus the overprint colors (RGB) plus the paper values. It then generates the gamut hexagon and comparisons can be made. Although the color gamut is a three-dimensional object the gamut plots shown here are two-dimensional.

An example of a gamut plot of the pure proofing colors in comparison to the standard press sheet is shown below.

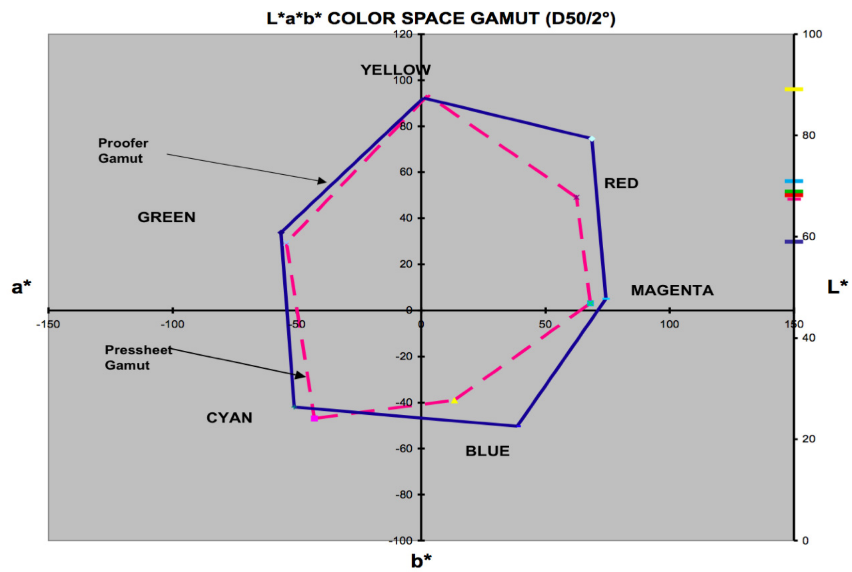

Figure 8 Typical Gamut Plot between press sheet (Dashed line) and a proofing solution (Inkjet 2) without color management

From figure 8 it would appear that the proofer is operating in a mode that ensures a press to proof gamut match. The gamut plots from the other proofing systems have a similar appearance.

Metamerism

Metamerism is defined as the tendency for color to shift hue as it is viewed under different lighting conditions.
The available yellow colors were compared to the standard using a built-in function in QA 2000 to determine the metameric index. This function is based on DIN 6172. It compares the L*a*b*-numbers of the standard and the sample under two illuminants.

The metameric index is calculated after the following equation:

$$MI = \sqrt{\left(\Delta L*_1 - \Delta L*_2\right)^2 + \left(\Delta a*_1 - \Delta a*_2\right)^2 + \left(\Delta b*_1 - \Delta b*_2\right)^2}$$

with 1 = Illuminant 1 and 2 = Illuminant 2 and Δ = Value sample minus value standard.

It gives the relative color difference between illuminants.
The chosen illuminants were D50/10° (standard illuminant) and F2/10° (Cool white fluorescent).

The metameric indexes for the yellow colorants are listed below:

Yellow	**Metameric index**
Standard	N/A
Inkjet 1	4.69
Inkjet 2	2.93
Inkjet 3	3.80
Laser 1	3.94
Laser 2	3.16
Laser 3	3.74

Table 5: Metameric index of the compared yellow prints between illuminant D50/10° and F2/10°

The yellow colorants show some metamerism. The lowest metameric index is observed for Inkjet 2 and the outside supplied press sheet, while the highest index occurs in the yellow color of Inkjet 1. The calculation of the metameric index is very similar to the DE (CIE) calculation therefore a similar weighting of color difference can be applied. The following weighting scale is used (Heidelberg, 1995):

MI = 0 – 1	Barely noticeable
MI = 1 – 2	Small deviation, perceivable by an experienced eye
MI = 2 – 3.5	Medium deviation, perceivable by an inexperienced eye
MI = 3.5 – 5	Large deviation
MI > 5	Massive deviation

Using this weighting scale only the outside supplied press sheet can be classified as a small deviation. The metameric index for Laser 2 and Inkjet 2 are considered a medium deviation and Inkjet 1 and 3, Laser 1 and 3 show a large deviation. Even the inexperienced eye can observe the medium and large deviations. Only the colorants used in Inkjet 2 and the yellow pigment used to print the outside supplied pres sheet show an acceptable variance from the standard.

The biggest differences occur between the standard press sheet and Inkjet 1 and Laser 1.

The spectral curves of the three yellows in question are shown below:

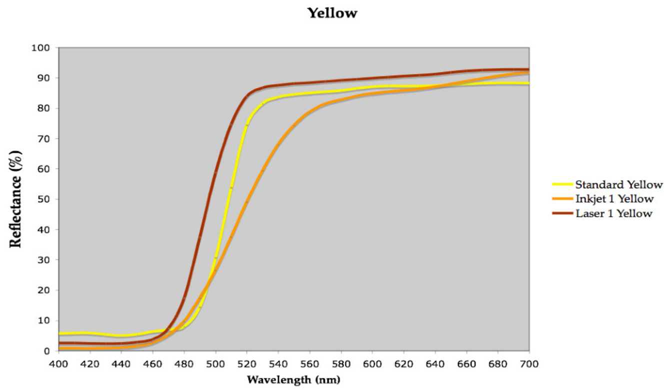

Figure 9 Yellow spectral curves of the standard yellow and inkjet 1 and laser 1

All three colors show quite different reflectance curves. These different reflectance curves give a different color impression under varying lighting conditions due to the different wavelengths at which the reflectance values increase from around 10% to their maximum reflectance values. The spectral curve of the Laser 1 yellow has more blue/green components then the standard yellow, while the Inkjet 1 has more yellow/red components in its reflectance curve. These differences in the reflectance curves correlate also with the observed hue angle differences.

After the metameric index for yellow colorants has been evaluated the magenta colors were assessed as well. The metameric indexes for the magenta colors are shown in table 6.

Magenta	**Metameric index**
Standard	N/A
Inkjet 1	3.68
Inkjet 2	3.93
Inkjet 3	1.09
Laser 1	1.29
Laser 2	1.41
Laser 3	1.05

Table 6: Metameric index of the compared magenta prints between illuminant D50/10° and F2/10°

Based on the previous introduced weighting scale 4 out of 6 magenta proofing colorants show a small deviation that can be perceived by an experienced eye. The proofing colorants labeled Inkjet 1 and 2 show a large deviation from the standard based on the weighting scale listed above.

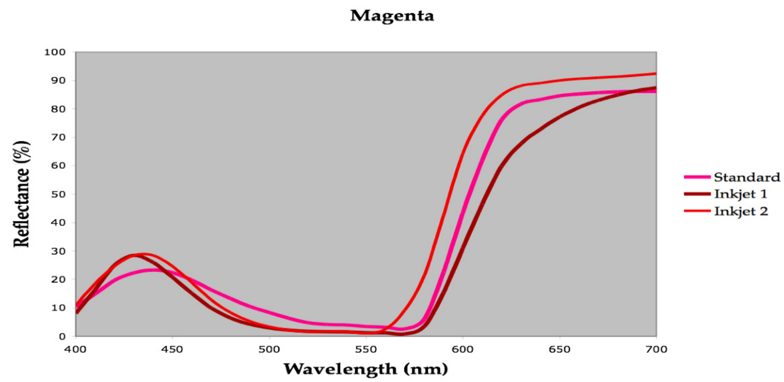

Figure 10 Magenta spectral curves of the standard Magenta and Inkjet 1 and Inkjet 2

The reflectance curves between the standard and both inkjet solutions are quite different, especially between the standard and inkjet 1. These curves will give different color impressions under different light sources, because Inkjet 2 has more green components in its spectral curve then Inkjet 1. Inkjet 1 contains more yellow/red components. These differences are in line with the observed hue angle differences.

After the metameric index for magenta colorants has been evaluated the cyan colors were assessed as well. These numbers are listed in Table 7.

Cyan	**Metameric index**
Standard	N/A
Inkjet 1	0.40
Inkjet 2	0.41
Inkjet 3	1.79
Laser 1	1.46
Laser 2	0.27
Laser 3	1.42

Table 7: Metameric index of the compared cyan prints between illuminants D50/10° and F2/10°

The numbers for metameric index for cyan are the lowest numbers in this study. Barely any color shift will occur in these colors between D50/10° and F2/10°.

The spectral curves of the colors with the lowest and the highest meta–meric index are shown in the following figure.

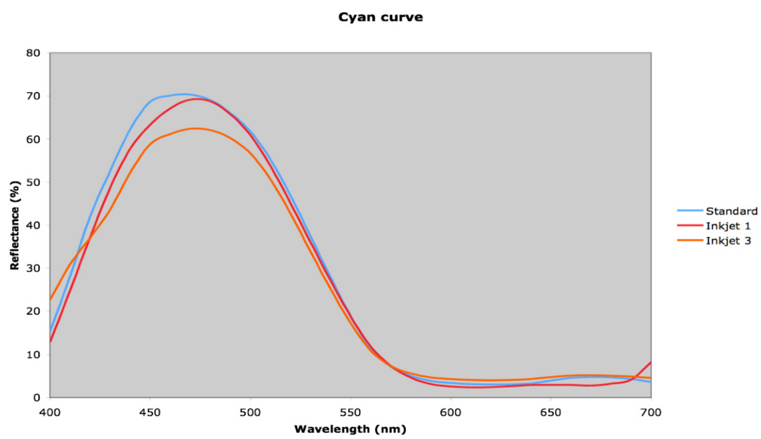

Figure 11 Spectral curves of the cyan colors with the lowest metameric index (Inkjet 1) and the highest metameric index (Inkjet 3)

The spectral curves of the standard and Inkjet 1 are almost identical, while the curve from Inkjet 3 has a lower reflectance maximum and more violet and less blue spectral components which account for the different color impression under the secondary light source (F2/10°).

Conclusions

All the obtained results can be summarized in the following table that also gives a weighting of the differences:

	Color difference $DE_{CMC2:1}$	Hue difference	Metameric Index
Yellow	++	More green/more yellow	+++
Magenta	+++	More blue/more red	++
Cyan	+	More yellow (Inkjet) More red (Laser)	+

+ = small difference, ++ = medium difference, +++ = large difference

Table 8: Weighting of the results

This table shows that the cyan color can be proofed quite close to the cyan used in offset printing inks. An interesting result is that the laser toner based systems use a more reddish cyan and the inkjet based systems use a cyan that is more towards a yellowish cyan.

Magenta colors used in the proofing systems show the largest color difference and a medium metameric index. Most magenta colors are bluer then the magenta used for manufacturing offset printing inks.

The evaluated yellow colorants show the highest metameric index in comparison to the two other colors. Most yellow colorants are greener compared to the yellow set as standard.

The metamerism of the compared yellow colors can be visible in pictures that contain neutral grey colors made of CMY. If the press sheet has been balanced for a neutral grey then the proof would probably have
a.) a colorcast under normal viewing conditions and
b.) under different lighting conditions then 5000K press light.

The evaluation of the color gamut showed that the gamut of proofing device has been set-up to be similar to that of a press sheet.

Today’s proofing solutions are quite capable of accurately reproducing four color process inks. The color differences have been minimized through either
a.) colorants with a similar spectral curve then pigmented four color process inks and
b.) through color management and ICC profiling.

Although the samples have been randomly collected the results show that the colorants of the various proofing solutions are quite close to the four color process inks. Metameric effects can occur under different lighting conditions then standard press light viewing conditions.

It seems the days were printers asked their ink manufacturer to match their process colors to the colors of the newly purchased proofing solution are a thing of the past. Color management and ICC profiling will help to better match up press and proof.

It would be better if the proofing and printing colors match each other spectrally. The smaller the difference is between process ink and proofing colorant the lesser work color management has to do to correct the shades of the colorants on how they will be perceived by the human eye. Other factors that have to be taken into consideration are the properties that inkjet ink or laser toner need to have, so they have excellent printing characteristics. May be it is not possible or quite difficult to have proofing colorant and offset printing ink match each other but the manufacturers of inkjet inks and laser toners can answer this question better. In an ideal situation where the spectral curves of printing ink and proofing colorant are almost identical little or no color management would be necessary.

References:

Felici, J.,
Inkjet Proofing Goes Mainstream, The Seybold Report on Publishing Systems, Vol.4. Number 6, pp 7 – 9, 2004

Fraser, B., Murphy, C., Bunting, C., Real World Color Management, Peachpit Press, ISBN 0-201-77340-6, 2003, p. 184

Heidelberg Publications, Colour and Quality, 1995, p. 81,

IPA,
IPA Special Report, Color Proofing RoundUP Results, September 2005

Livens,S. et al.,
Consistent Inkjet Proofing with a Quality Management System, TAGA Proceeeding 2002

Paul, A.
Bekennen Sie Farbe – kraftvoll und nuanciert, Der Druckspiegel, p. I – VII, Sonderbeilage, 1998

Paul, A.
FOGRA Forschungsbericht 50.026, 1998

Shyu, M.,
A Study of the Printing Ability and Feasibility of the Color Ink Jet Printer in Color Proofing, TAGA Proceedings, 1999