Lightfastness Properties of Different Digital Printers and Papers

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Abstract

The objective of these experiments is to determine the lightfastness properties of various inks and most common digital printing methods. Lightfastness is the degree to which a dye or ink resists fading due to light exposure. Each ink has a different degree of resistance to fading by light. Because light is energy, the energy that is absorbed by pigmented compounds degrades the compounds or nearby molecules. The experiments described in this document involve printed samples subjected to equal amounts of sunlight exposure using accelerated methods. Statistical analysis comparing before and after data include average color change in terms of ΔE and overall gamut volume is compared. From these calculations, resistance to lightfastness can be accurately quantified.

Introduction

Although the digital age is here and some paper-based communications are declining, there are still many situations where color accuracy over time is desired. One way to predict the longevity of a digitally printed document is to measure the lightfastness properties. Wilhelm describes lightfastness as the ability of pigment and dye-based inks to maintain accurate color strength over time due to light exposure fading and lightfastness [1]. Situations with desired color permanence include individuals wishing to capture and print digital photographs, art, books, journals, and posters. In recent decades, printing of these materials has shifted from outsourcing to local print shops to printing in the home and office. This shift has been made possible in large part due to the development of digital printing technologies that are becoming more affordable and are now standard in the office and the home [2]. However, not much has changed in how people handle, store, and expect materials to perform over time. To the average consumer, an inkjet print is considered to be just as much a 'photograph' as the color prints made on RC photo papers that have been hanging on walls, stored in albums and shoeboxes, and carried in wallets for many years [3]. With the flood of new home and office printers arriving on the market everyday and the large variety of papers now available, there is no understanding of image permanence of digitally printed media because of how new digital printing is itself. In other words, there is no way to tell how long digitally printed media might last when compared to photos and other media printed in traditional ways. Currently, there is no industry wide standard for evaluating the longevity of digitally printed media. This is due in part to the fact that there has been no demand for this knowledge; people simply accepted what was given. Another reason is the difficulty and time it takes to accurately measure the color of something that is printed. Ideally, to precisely measure the longevity of a print, samples would have to be stored in normal everyday conditions in homes, offices, and storage areas and patiently wait months or even years for results [3]. However, these real time tests are not practical or fast enough for research and development, because by the time the test is complete, methods and materials used may be out of date or obsolete. This problem is addressed using accelerated lightfastness testing methods. Accelerated testing exposes samples to intense light for hours or days, which simulates months or years of light exposure. Thus, results are acquired at a faster rate increasing the speed of research. For these experiments accelerated methods are employed. Similar methods for measuring lightfastness have proven to be successful.

Recently, Chovancova-Lovell et al., working in our research group, have developed a test method for investigating the lightfastness properties of various dye-based and pigment based printers [4-6]. These methods proved to accurately measure ΔE, the change in color, between exposed and non-exposed samples. The key to process was determining the full range of colors, or gamut, for the given printer/ink/substrate combination. This is accomplished by measuring a test chart, such as the ECI2000 [7] with sufficiently many patches to span the full gamut of the printer. Indeed, the color gamut with a given printing device has recently been proposed as a tool for papermakers to characterize their manufactured paper [8]. The lightfastness is then characterized by reprinting test chart after the accelerated aging test and noting the change/decrease in color gamut. The ΔE and change in color gamut are then used to quantify the lightfastness. Lightfastness has been seen to be strongly dependant on paper, ink and printing device properties [4-6,9].

Although this research done in this paper emulates many of Chovancova, et al.'s methods, there are some factors that have changed. This experimental procedure has been refined to accommodate for testing thermo-sensitive ink sets, which require maintaining a lower chamber temperature. This research also tests the different pigment and dye-based printers with updated ink sets such as the Epson Ultra Chrome K3 ink set. The goal of this research is to provide the consumer, printer, ink, and paper manufacturer valuable R&D and image permanence data and test methods to help evaluate and improve the longevity of future products. This research also provides future researchers a set of dependable methods to accurately gauge the relative performance of future products. Results of these experiments will enable manufacturers to understand market position and product longevity.

Methods

These experiments test the following three digital printers:

- Xerox 8550, loaded with the OEM CMYK dye-based solid ink sticks printed on Sappi Somerset 70lb glossy offset paper.
- Epson Stylus Pro 9800, loaded with the 8-color Epson UltraChrome K3 Ink printed on Premium Semimatte Photo Paper (250) substrate.

- Xerox Docucolor 12 Color Laser printer using the OEM CMYK toner cartages printed on Sappi Somerset 70lb glossy offset substrate.

In order to achieve accurate results, a workflow that accommodates all substrates and printers must be established. First, each printer is loaded with its optimum ink and comparable substrate. The ECI2002 random test chart is obtained from www.eci.org. The ECI 2002R (Figure 1) chart offers over 1,400 data points and contains a random layout that helps prevent print head fatigue. The workflow of the Epson Stylus Pro 9800 differs slightly at this point from that of the Xerox Phaser 8550 and the Xerox Docucolor 12. The Epson's workflow requires the TC9.18 RGB color chart (Figure 1) because; although the 9800 is a CMYK device, the printer driver used treats it as an RGB device [10,11]. This is a crucial step for achieving accurate results. Using the RGB driver alone reduces steps in the experiment and has been shown to provide a large color gamut [10]. The test chart is then opened in Adobe Photoshop CS 2 for output.

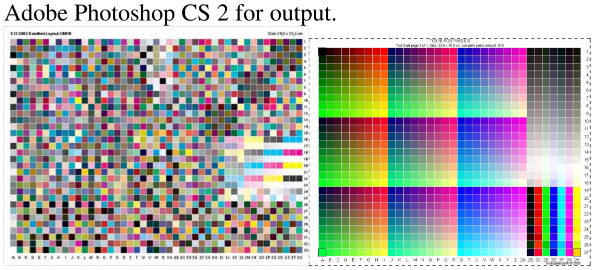


Figure 1 ECI2002R color test chart (left) TC9.18 (right)

Each printer should be set to optimum print quality and color management software should be turned off at this time. This is achieved through the print with preview menu by choosing 'File > Print With Preview'. Samples printed using the Epson Stylus Pro 9800 must also be output this way only using the TC9.18 RGB chart. Also, samples printed using the 9800 must wait a minimum of 12 hours before proceeding onto the next step so that samples stabilize [4-6]. In one study it was shown that "The ink/substrate combinations reach constant values about 6 hours after output."[6] Because the Epson 9800 uses slightly different inks than the one in that study, a 12-hour waiting period was used to ensure stabilization. After the prints stabilize, a GretagMacbeth SpectroScan spectrophotometer and GretagMacbeth Measure Tool software were used to record L*a*b values for each patch on the test chart creating a ''*before*'' data set. Once the L*a*b values are recorded in raw form of data, they are loaded into the GretagMacbeth Profile Maker pro software. This software is used to generate an ICC profile [11]. This profile is an essential form of data for Color Think Pro 3.0, which will be used for gamut volume calculations and 3-D graphing below. Once each sample has been printed and measured it is exposed to accelerated sunlight exposure. The Sunset CPS+ Atlas lightfastness chamber (Figure 2, the same unit used by Chovancova-Lovell et al.) exposes samples to a 51 hr cycle in 6 phases. Phases 1,3, and 5 consist of 16 hours of light exposure. Phases 2,4, and 6 consist of a 1-hour rest phase.

Figure 2 Sunset CPS + Lightfastness chamber

The entire sequence is 16 hours on, 1-hour off, 16 on, 1 off, 16 on, and 1 off. This exposure cycle equates to 129,600 KJ/m^2 of light or roughly 6-months of light exposure in noonday sunlight [4-6]. It is also critical to set the BST (Black Square Temperature) sensor is set to the chamber minimum setting of 35 degrees Celsius in an effort to maintain the lowest possible chamber temperature.

Upon conclusion of light exposure, each sample must undergo measurement with the spectrophotometer again. These measurement creates an ' after' picture of the exposed test chart. The before and after data sets are analyzed using the ΔE equation which is expressed as [12]:

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

In this case, L1, a1, and b1 represent the before data and L2, a2, and b2 represent after data. ΔE calculations are quickly done using a Microsoft Excel spreadsheet. Within this spreadsheet, individual ΔE's for each data point are calculated and an average is taken.

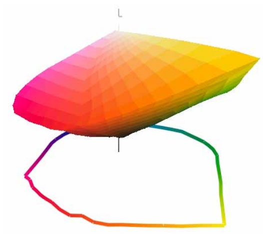
Results

After proceeding through the methods described above, the following results were found. It was observed that the greatest color shift occurred in the Xerox Phaser 8550. The Xerox Docucolor 12 had the smallest shift in gamut volume followed by Epson Stylus Pro 9800. Reviewing the gamut volume calculations from Color Think Pro demonstrates this color shift. The 8550 started with an overall gamut volume of 291,223 and ended with a gamut volume of 102,465; this is a change of 188,758! The Docucolor 12 had 4,177 while the Epson had a difference in gamut volume of 24,571. The significant gamut reduction after light exposure for the Phaser 8550 is typical of dye-based inks [4,5,13]. The smaller gamut reduction for the DocuColor 12 and the Epson 9800 is typical of pigment based inks [4-6].

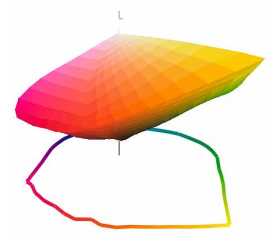
Table 1 Summary of simulated fading results.

Name	Before Gamut Vol.	After Gamut Vol.	Difference Gamut Vol.
Epson StylusPro9800	604,711	580,140	24,571
Xerox Docucolor 12	302,553	298,376	4,177
Xerox Phaser 8550	291,223	102,465	188,758

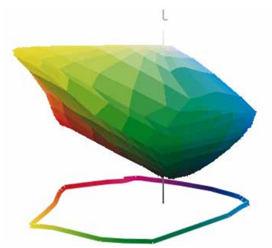
In Figure 3, each printer's color shift is represented by before and after 3-D graphs representing L*a*b color space.



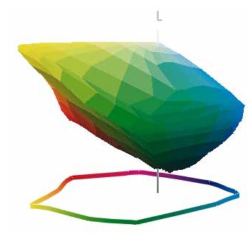
Epson 9800 Pre-Exposure.



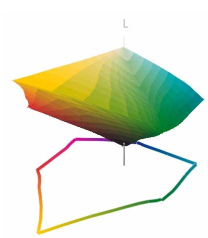
Epson 9800 Post Exposure



Docucolor 12Pre-Exposure



Docucolor 12 Post Exposure



Phaser 8550 Pre-Exposure

Phaser 8550 Post Exposure

Figure 3. Graphical depiction of before and after gamut volumes.

Lastly, the average ΔE is shown in Table 2. It was observed that the Epson Stylus Pro 9800 had the lowest average ΔE of the three printers tested with a ΔE of 1.54. The Docucolor 12 was next with an average ΔE of 2.27. Again, the Xerox Phaser 8550 underwent the greatest color change with a recorded average ΔE of 26.46.

Table 2 Summary Average ΔE

Name	Average ΔE
Epson StylusPro9800	1.54
Xerox Docucolor 12	2.27
Xerox Phaser 8550	26.46

Summary and Conclusions

This set of experiments was performed using three different digital printers utilizing different inks and methods of printing. Experiments were performed with the intent of testing each sample for its lightfastness properties. Each sample was measured using a spectrophotometer where before and after simulated light exposure data was recorded. Then profiles, gamut volume measurements, and ΔE calculations were performed. For the most part samples held up better than expected with the exception of the Xerox Phaser 8550. The color shift in the 8550 was most apparent when reviewing the change in gamut volume and the average ΔE. The probable reasons for such a great shift are that the wax based inks of the 8550 fail under the heat of the chamber lamp and the use of dyes, instead of pigments for these inks. We expected a larger color change for these dye based inks, but it is larger than observed previously for dye-based inkjet inks on their recommended substrates [4,5]. Dyes generally have poorer lightfastness than pigments [4,5,9].

The Epson Stylus Pro 9800 had the smallest shift followed by the Xerox DocuColor 12. Both of these are based on pigments, liquid dispersed for the 9800 and in dry powder form for the DocuColor 12. That being said, another method may be needed to accurately measure the lightfastness or image permanence of the Xerox 8550. An improved method for testing the 8550 may include a lightfastness chamber that is equipped with temperature controls that keep the sample cool enough. These findings can be useful to printer and ink manufacturers alike for image permanence data and product specifications. Results can also be used by marketing departments as well as a starting point for further research on digital image permanence.

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