High-Intensity Fluorescent Light-Fading Tests for Digital Output Materials

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Abstract

Digital hard copy output has increased dramatically as an alternative to traditional imaging systems. From family pictures output by home computers to commercial signage and art reproduction, companies are rushing to get a piece of the digital pie. At first, the problems of resolution, printing technology, color reproduction and digital capture were the center of attention. With advances in solving these issues and the resulting increase in demand for the new products come new questions. A customer will marvel at the ease of use, the acceptable image quality and speed of editing, but now that same customer will ask, “How long is it going to last?”

In the digital world, new output technology, new ink sets for existing devices and new media are appearing every day. With these developments comes the need to reassure the consumer that the new products will have a usable life adequate to the proposed application. In traditional photography, there is a battery of accelerated tests to compare and predict life expectancy of both the image and the support. Until now, tests of digital hard copy materials have had to rely on the precedents established by the photo industry. The Image Permanence Institute has constructed a high-intensity (50 to 100 klx) fluorescent light-fading apparatus aimed at giving fast answers to questions about display life of digital hard copy output images. After comparative tests at different light intensities, it has been determined that some inkjet materials do not suffer from reciprocity law failure common to photographic materials. This means that high-intensity, short-term tests can be a reliable indicator of long-term stability in these materials.

Introduction

Inkjet imaging is becoming a predominant method for production of fine-art prints. The non-impact-printing field considers speed and image stability to be the primary weaknesses of inkjet technology.[1] It is therefore becoming more and more important that these types of images have, at least, a permanence rivaling conventional photographic materials, the current benchmark for stability among image-makers. For prints on display, light stability is particularly critical.

Technological changes in this field are rapid, and it is important that reliable test results be produced in the shortest possible time. In light-fading tests, acceleration is achieved based on the reciprocity law by using higher intensity lights. The reciprocity law simply states that the amount of photochemical change is constant for any constant exposure where exposure is defined as intensity × time. For light fading experiments, this law says that the same degree of fading should occur with ten times the intensity in one-tenth the time. The limitation of this law occurs when the intensity is high enough that the fading-rate determining factor is no longer radiant energy but diffusion of oxygen and/or water into the system and/or diffusion of deterioration byproducts out. At this point, the fading of colorants takes longer than the reciprocity law would predict, and reciprocity law fails. Further limitations may appear if the radiant heating by high-intensity lights becomes significant enough that conventional air-cooling can no longer compensate. Depending on the specific reactions involved, one of two things may happen. Radiant heating may supply enough energy to the system to speed up thermally-dependent fading reactions, or the higher temperature may reduce the equilibrium moisture content of the paper enough that the fading rate slows down. In theory, localized radiant heating will be dependent on the spectral distribution of the light and the absorption spectra of the individual patches.

50 to 100 Klx Light-Fading Apparatus

Until recently, accelerated light-fading tests have used Xenon-arc apparatus to simulate either direct sunlight or sunlight through window glass. In reality, most images in home or office situations are exposed not to sunlight but to many hours of fluorescent light per day. Tests involving fluorescent lighting are generally of low intensity as seen in the ANSI standard cool-white fluorescent test IT9.9 where 6 klx is specified. The light stability of current inkjet prints is improving, and with this improvement comes the necessity for feedback on light-fading characteristics in a reasonable time frame. The IPI high-intensity fluorescent unit is designed to offer ten years of simulated office exposure (at 100 klx) in eight days.

The fluorescent test fixture built for IPI was custom designed under a private contract by Richard Codori of Eastman Kodak Company. This unit uses forty-two GE F72T12CW 1500W cool-white outdoor fluorescent tubes. These lamps are divided into groups of three resulting in 14 separate circuits and on/off switches. These separate circuits make it easier to pinpoint bad lamps. Each circuit is powered by a transformer. The lamps are mounted vertically in the lamp frame with 21 lamps on each side of the fixture. They are placed as close together as possible to minimize cold spots at the sample plane. The lamp frame itself is equipped with large casters on the bottom that allow the fame to be moved. A small 3.3-rpm electric motor slowly and continuously moves the lamp frame back and forth. Moving the lamp frame acts to homogenize the light at the sample plane, reducing the effects of gaps between individual lamps and the curvature of the lamps themselves.

Samples are mounted in aluminum channels in two panels on either side of the lamp frame. The channels can be adjusted to sample size. In the current configuration, thirty-two 8.5 x 10.25-inch samples can be tested. Light intensity can be adjusted by moving the sample panels in or out as needed. It is possible to maintain any intensity level between 50 and 100 klx.

Example of Test Procedures and Results

Most of the fluorescent light-fading, work performed at IPI is custom-designed according to manufacturers' different needs. Some companies want to look at new ink sets while others may have a media-yellowing problem. No matter what the customer wants, computer routines must be written to manipulate the data. This is a costly part of each individual project. Perhaps when the introduction of new materials slows down standardized tests can be developed for specific characteristics.

The focus of this paper is to introduce the utility of high-intensity fluorescent as a quick, accurate way to investigate particular problems or new materials. The following discussion uses actual data, without reference to specific products or manufacturers. It is intended to serve as an example of reporting possibilities and problem solving. In this example, the customer wanted to make a quick comparison between their own ink sets and some of their competitors' inks. Further, they wanted to see if their inks suffered reciprocity law failure in ways similar to those of photographic products.

Procedure

Samples of four inkjet images identified as P, C, F and H were exposed for up to 16 days with 50 klx fluorescent light, equivalent to approximately ten years of exposure under average office lighting assuming reciprocity law compliance. An additional sample of image P was exposed for up to 120 days with 10 klx fluorescent light, equivalent to approximately 15 years of exposure under average office lighting. The samples consisted of density step wedges of pure cyan, pure magenta, pure yellow, red, green, blue and neutral as well as an image [N7 "Musicians," from *ISO 12640:1997 Graphic technology – Prepress digital data exchange – CMYK standard color image data (CMYK/SCID)*]. GE Cool White Outdoor tubes were used in the 50-klx unit, and Sylvania Cool White Deluxe tubes were used in the smaller 10-klx unit.

Predictions were made using the endpoint values selected and popularized by Henry Wilhelm.[2] Cyan, magenta and yellow colorants were measured using Status A red, green and blue filters, respectively (as defined in *ANSI/NAPM IT2.17-1995 Photography – Density Measurement – Part 4: Geometric Conditions for Reflection Density and ANSI/NAPM IT2.18-1996 Photography – Density Measurements – Part 3: Spectral Conditions*), on an X-Rite 310 Densitometer. All calculations from these measurements, other than the predictions, were performed in accordance with *ANSI/NAPM IT9.9-1996 American National Standard for Imaging Materials – Stability of Color Photographic Images – Methods for Measuring*.

Since it is so difficult to produce patches at very specific densities, the standard allows the use of linear or cubic spline interpolation. For this project, linear interpolation was applied. It should be noted that conventional color photographs can produce non-pure color density patches such as neutral with fairly constant relative proportions of the component dyes. This is much more difficult to achieve with digital images. This means that the relative proportions of cyan, magenta and yellow dyes in a "neutral" gray scale can vary significantly from patch to patch. This effect influences the fading rates of each dye from density patch to density patch and therefore also the interpolated values. The problem theoretically can be corrected with a large amount of calibration work, but it did not seem to warrant the time or effort. The endpoints used in this study are given in Tables 1 and 2.

Red, green and blue patches were included on these samples requiring the additional endpoints shown in Table 2. The endpoints are taken from Wilhelm's recommendations shown in Table 1, although red, green and blue density patches are not specified by ANSI or Wilhelm.

Results

Primary properties are those that are directly measured such as cyan dye loss in a pure or neutral patch. All color balance values are secondary properties derived or calculated from primary measurements. Only the primary measurements are of value in determining the level of reciprocity failure in light fading tests, since the color balance values depend on the *relative rates* of fading of pairs of dyes.

Reciprocity law failure does not appear to be a problem with sample P. In only three out of eight pairs of endpoints reached were the predictions made at 50 klx higher than the 10 klx values. With the small sample size at 10 klx and the possible random cumulative errors, one would expect some predictions to be higher at 50 klx and some to be lower.

It is also interesting to note that for all properties that reached endpoints in patches 1.0 and 0.6 density units above Dmin, predicted times to endpoints were very similar. In almost all cases, the endpoint times for the 1.0 density patches was higher than for the 0.6 density patches as is found with conventional photographic imaging materials.

Table 1. Endpoint limits.

Property	Endpoint	Notes
Pure cyan patch	25% loss	
Pure magenta patch	20% loss	
Pure yellow patch	35% loss	
Cyan in neutral patch	25% loss	
Magenta in neutral patch	20% loss	
Yellow in neutral patch	35% loss	
Cyan-magenta color balance in neutral patch	+12% and –15%	+ shift toward cyan, – shift toward magenta
Cyan-yellow color balance in neutral patch	±18%	+ shift toward cyan, – shift toward yellow
Magenta-yellow color balance in neutral patch	±18%	+ shift toward magenta, – shift toward yellow
Cyan in Dmin	+0.06 density units	Cyan stain
Magenta in Dmin	+0.06 density units	Magenta stain
Yellow in Dmin	+0.15 density units	Yellow stain
Cyan-magenta color balance change in Dmin	±0.05 density units	+ shift toward cyan, – shift toward magenta
Cyan-yellow color balance change in Dmin	±0.10 density units	+ shift toward cyan, – shift toward yellow
Magenta-yellow color balance change in Dmin	±0.05 density units	+ shift toward magenta, – shift toward yellow

Table 2. Additional endpoint limits.

Property	Endpoint	Notes
Cyan in green and blue patches	25% loss	
Magenta in red and blue patches	20% loss	
Yellow in red and green patches	35% loss	
Cyan-magenta color balance in blue patch	+12% and -15%	+ shift toward cyan, – shift toward magenta
Cyan-yellow color balance in green patch	±18%	+ shift toward cyan, – shift toward yellow
Magenta-yellow color balance in red patch	±18%	+ shift toward magenta, –shift toward yellow

Table 3. Years of Simulated Home/Office Exposure to Reach Endpoint Limits[*]

Property	**0.6 above Dmin**		**1.0 above Dmin**	
Intensity →	**10 klx** [†]	**50 klx** [††]	**10 klx** [†]	**50 klx** [††]
Pure Cyan				
Pure Magenta	12	7		
Pure Yellow		9		
Neutral (C)				
Neutral (M)	7	7	6	7
Neutral (Y)				
Red (M)	9	6	9	7
Red (Y)				
Green (C)				
Green (Y)				
Blue (C)				
Blue (M)	4	5	4	6
Neutral (C-M)	5	6	4	6
Neutral (M-C)				
Neutral (C-Y)	13			
Neutral (M-Y)				
Red (M-Y)				
Green (C-Y)	11		11	
Blue (C-M)	2	4	2	4

[*] Extrapolations of display time assume 450 lx, 12 hours per day of light exposure.

[†] Empty cells did not reach endpoint and therefore are “greater than 15 years of simulated office display” tested with 10 klx fluorescent light.

[††] Empty cells did not reach endpoint and therefore are “greater than 10 years of simulated office display” tested with 50 klx fluorescent light.

Table 4. Years of Simulated Home/Office Exposure to Reach Endpoint Limits*

Property	**Sample P (10 klx)**		**Sample P (50 klx)**		**Sample C**		**Sample F**		**Sample H**	
Density patch	**0.6**	**1.0**	**0.6**	**1.0**	**0.6**	**1.0**	**0.6**	**1.0**	**0.6**	**1.0**
Pure cyan							4	5		
Pure magenta	12		7		6	7	2	3	3	4
Pure yellow			9				3	3		
Neutral (C)					10	8	3	3		
Neutral (M)	7	6	7	7	6	6	4	4	4	5
Neutral (Y)							5	6		
Red (M)	9	9	6	7	7	7	2	3	2	3
Red (Y)							4	5		
Green (C)					9	8	3	3		
Green (Y)							4	5		
Blue (C)							3	3		
Blue (M)	4	4	5	6	6	5	4	4	4	6
Neutral (C-M)	5	4	6	6			7		4	5
Neutral (M-C)										
Neutral (C-Y)	13						6	9		
Neutral (M-Y)						10	10		5	6
Red (M-Y)					9				5	5
Green (C-Y)	11	11					5	6		
Blue (C-M)	2	2	4	4	10	9	8		4	6

* Extrapolations of display time assume 450 lx, 12 hours per day of light exposure.

Times to reach endpoints under simulated average office conditions are summarized below. Dmin stain and Dmin color balance changes did not occur and have been excluded from the table for brevity.In terms of overall fading in the neutral patch 1.0 density units above Dmin, sample P performed quite favorably relative to samples C, F and H, although in some of the color balance parameters, it did not perform quite as well.

Sample P does not appear to suffer from significant reciprocity failure, and it is possible to make reasonably good predictions regarding its life expectancy using data from the faster 50 klx test.

Sample P performed quite well with regard to general fading compared to products C, F and H. The results are briefly summarized in Figure 1.

Also included in a report of this kind are line graphs comparing the relative behavior of the sample materials in reaching each end point. Only one of these graphs are included in this paper as they represent over 40 individual graphical objects. Figure 2 is a typical representation of comparative data. The graphs help in visualizing the data and are an essential part of a normal report.

Conclusions

High-intensity fluorescent light-fading tests can be a viable gauge of relative resistance or susceptibility of inkjet inks and media to exposure under office conditions. It can also be helpful in pinpointing problems with individual inks or ink-media combinations. Fast results are important in such a dynamic marketplace.

Some problems exist with this prototype unit that need to be addressed. One problem that consumes a lot of labor is that samples must be individually mounted and numbered, because of the intensity fall-off from top to bottom and side to side of the sample plane. A sample rotation plan must be initiated to insure equal exposure of all samples. Other problems involving specific mechanical choices can be addressed if new units are constructed.

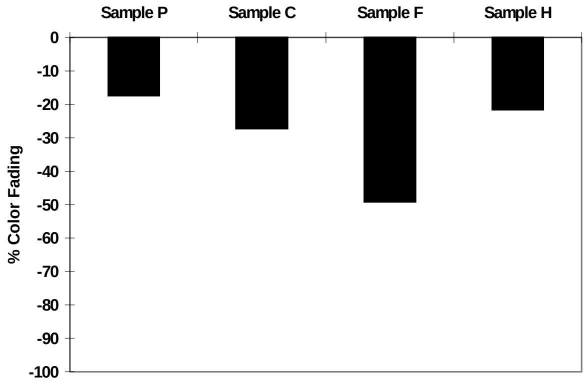

Figure 1. Comparative fading after 10 years of home/office display. Average dye density loss from 1.0 density neutral image area exposed 384 hours to 50 klx cool-white deluxe fluorescent lamps. Extrapolations of display time assume 450 lx, 12 hours per day of exposure to light.

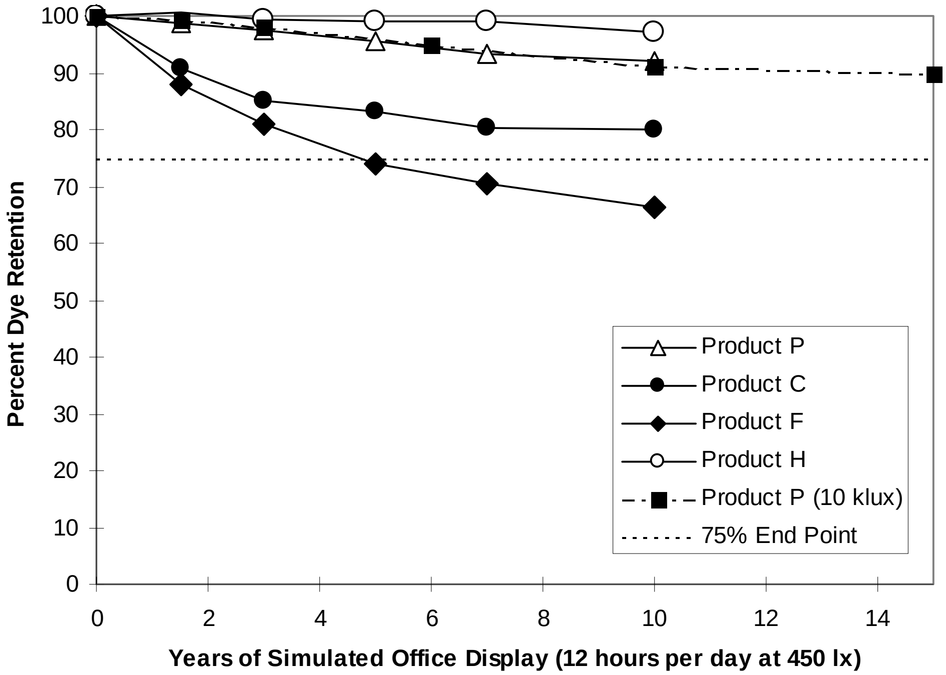

Figure 2. Percent dye retention for pure cyan patch 1.0 density units above Dmin during exposure to 50 klx fluorescent light.

References

1. A. Jaffe, "Printer Wars: What Will Survive?" Presentation at IS&T Rochester Chapter Meeting, Rochester, NY, April 15, 1998.
2. H. Wilhelm with C. Brower, contributing author, *The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures*, Preservation Publishing Company, Grinnell, Iowa, 1993, pp. 78-79.

Biography

Edward Zinn received his B.A. from the University of Oregon and obtained his Master's Degree in Museum Studies at Rochester Institute of Technology. Mr. Zinn has worked at the Image Permanence Institute for the past ten years. He has written several articles on the effects of atmospheric pollutants on photographic materials. His responsibilities at IPI include the design, construction, and operation of the pollution test apparatus and performance and analysis of color-fading studies.