Image Permanence Test Chamber Uniformity

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Abstract

The digital print industry is working toward the goal of adopting improved test methods for image permanence. One underlying assumption typically made in such testing is that the test chamber is providing consistent results for each sample regardless of where it is located or mounted. This study evaluated the uniformity of two Xenon test chambers and two ozone test chambers. Variation in the Xenon chambers was found to be much greater than in the ozone chambers. Moreover, unexpected responses, unique for each ink colorant, were seen in the Xenon chambers.

Introduction

Image permanence testing utilizes printed test targets composed of many patches of differing densities and colors in order to capture the wide range of possible ink combinations contained within actual consumer images. This is useful for finding which aspects of the print are most prone to deterioration over time. However, this approach assumes that each color patch is being exposed to the same conditions and would respond the same regardless of its location on the test target.

Furthermore, this same assumption is often made on a larger scale—that identical color patches on separate test targets located in different areas of the test chamber will have the same response. But is that really the case?

This paper describes an investigation into the uniformity of several test chambers used for Xenon light stability and ozone stability testing.

Experimental Results and Discussion

The following equipment was used in testing:

- Minolta T-10M Illuminance Meter
- Atlas Ci4000 Xenon Weather-Ometer
- Atlas Ci3000 Xenon Weather-Ometer
- SATRA/Hampden Model 903 ozone chamber
- Lunaire CEO 910W-4 environmental chamber
- MAST Keystone Ozone Generator 700-10LTA
- Gretag Spectrolino/Spectroscan

The investigation began with a geometric analysis of two Xenon chambers. The Ci3000 consists of one rack; holding samples about 24cm from a Xenon lamp as they rotate about it. The sample is flat and based on the sample height, the distance from the Xenon lamp is slightly greater for color patches on the top and bottom of the sample than it is for patches at the center. Factoring in the difference in distance, the estimated light exposure should be 4% less at the top or bottom than in the center. Moreover, when taking into consideration the angle of the incident light, there is an additional 3% loss in intensity along the top and bottom of the sample. This was confirmed by taking measurements with a Minolta lux meter. The data shown in Table 1 includes several different sample loadings. The first is with no samples present, which reduces the amount of reflection, as light from the lamp travels further to the chamber walls before being reflected back. The second case is with only the white sample backing plates loaded in the sample holders. This maximizes the light intensity because the highly reflective white powder coating on these plates reflects the light as soon as it reaches the sample plane. The final case is with real test targets loaded into the sample holders. The light is reflected at the sample plane as before, but the various color patches also absorb part of the light. For each of these test cases the chamber light intensity control was kept constant, yet the light intensity at the sample varied. This happened because the samples can receive more reflected light than the control sensor, which is located closer to the lamp. One final observation about these measurements is that the lower part of the sample measured greater light intensity than the top of the sample, and this can be explained by the closer proximity of the bottom of the chamber to the samples than the top of the chamber to the samples—i.e., the bottom of the chamber was reflecting more light onto the sample than the top of the chamber.

Table 1. Illumination at different locations in the sample plane of Ci3000 (measured in klux).

	Position	No Samples	"White" Samples	"Real" Samples
Single Tier	High	74.5	77.5	76
	Center	79	83.5	81.5
	Low	76.5	81	78

The same types of measurements were made in the Ci4000, as shown in Table 2. The Ci4000 is larger, with three rotating racks on which samples may be placed. Reflection between samples is therefore a larger component of the total light exposure on any given sample.

Table 2. Illumination at different locations in the sample plane of Ci4000 (measured in klux).

	Position	No Samples	"White" Samples	"Real" Samples
Top Tier	High	68	82	77
	Center	70	85	80
	Low	69	84	79
Middle Tier	High	70	84	80
	Center	72	87	83
	Low	69	84	80
Bottom Tier	High	65	81	76
	Center	66	82	77
	Low	63	78	74

Based on the variation in measured light within the Xenon chambers, it was expected that there would be a corresponding variation in the fading of color patches at those locations. A new test target, shown in Figure 1, was created to examine the uniformity of fading. The test target consisted of 15 identical color patches oriented in columns of cyan, magenta, yellow, and black.

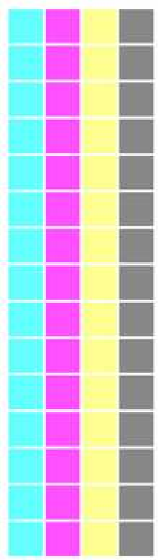

Figure 1. Test target for examining the uniformity of fading within test chambers.

Printers from three different manufacturers were chosen in the uniformity study. Samples were printed on each manufacturer's recommended porous photo paper; the inks were all dye-based. The first equipment evaluated was the Ci4000 Xenon light chamber. Samples were prepared and allowed to dry for 2 weeks in a controlled environment, and then all began testing simultaneously. One sample from each system was placed on the top, middle and bottom racks. The light intensity was set at about 80 klux (refer to 'Real' samples column in Table 2) and samples were measured after every 70 hours. Data trends were consistent at each measurement interval, so data will only be shown from the 280 hour measurement in this report.

Data was analyzed to show how each color patch faded with respect to the entire set from that system. For example, if a particular color patch faded 11% while the average fade rate of all patches of that color was 10%, then that color patch was fading at 110% of the average fade rate. Figure 2 shows measurement data from system 1; Figure 3 shows data for system 2; and Figure 4 shows data for system 3. Position 1 is the top patch of the test target in the top rack of the chamber, while position 47 is the bottom patch of the test target in the bottom rack of the chamber. Positions 16 and 32 are spacers to visually separate out the individual test targets at the top, middle and bottom of the chamber.

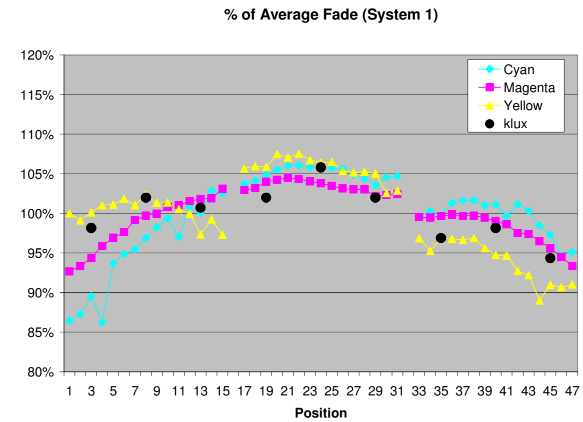

Figure 2. Percent of the total average fade for each color patch of System 1.

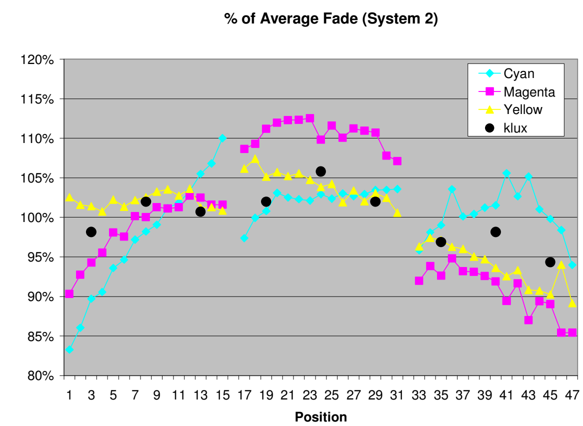

Figure 3. Percent of the total average fade for each color patch of System 2.

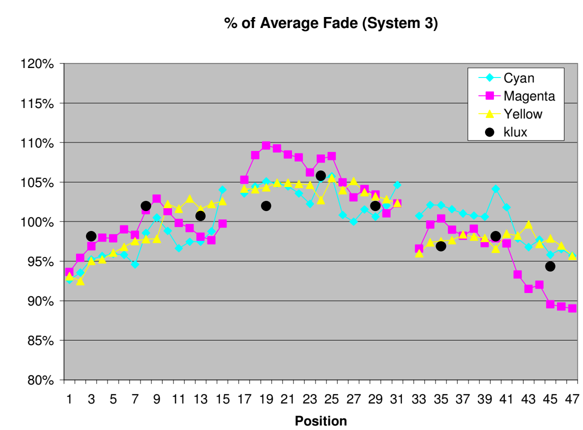

Figure 4. Percent of the total average fade for each color patch of System 3.

In each figure the expected fade rate based on the klux measurements are shown, with the highest values in the middle that taper off near the edges. The actual image fade rates do show similar trends to this, but it is not a perfect match to the variation in light intensity. One possible explanation for this discrepancy is a local variation in the spectral power distribution of the light caused by the reflection of nearby samples; it deserves some investigation but is expected to be a small influence. Another explanation is that the airflow across the samples is not uniform. The airflow enters the chamber from the bottom, but samples in the bottom and top rows are angled towards the lamp, which affects the angle of impingement of the airflow on those samples. There is less impingement on the bottom samples, even though they experience higher airflow. The Ci4000 is located in a lab with filtered air having less than 1 ppb ozone; nevertheless other air contaminants may be present and causing the samples to fade. Moreover, the incoming air in the chamber is not at the same temperature as the chamber, it is cooler in order to counteract the heating effect of the Xenon lamp. Samples near the air inlet may be exposed to cooler air with a corresponding higher relative humidity. This may cause dye migration, which temporarily counteracts the fading of the Xenon light. For example, the yellow ink of system 1 is more prone to dye migration from humidity, and it also happened to measure less fading at the bottom.

The second Xenon test chamber evaluated was the Ci3000, which has only one mounting rack centrally located to the lamp. For this test there were two sample replicates and the data were averaged together; moreover, the influence of airflow was also investigated. This was done because the Ci3000 chamber was located in a lab that did not have filtered air. A thin flexible polyester film (Melinex) was mounted directly on top of the test target, thus preventing any airflow from directly reaching the ink. Figure 5 shows data from system 2 without the Melinex present. Position 1 is at the top of the sample, position 15 at the bottom. The cyan ink faded much more near the bottom, likely a result of its closer proximity to the incoming air. As confirmation of this theory, Figure 6 shows another test target from system 2, but without airflow. In this case the fading of the color patches matches the predicted fade rate based on the light intensity measurements. Results from systems 1 and 3 were nearly identical to this behavior. Melinex was chosen for this study as it was inexpensive and readily available. Despite the promising results, it is not recommended for standard testing because of its aging characteristics and undesirable spectral transmittance profile.

Next, the investigation shifted to the ozone chambers located in the lab. Each was made by a different manufacturer with unique design principles: one being an open-loop system and the other a closed-loop system. The older MAST/Lunaire chamber had been modified several years earlier to fix design flaws which had caused variations of up to 20-25% between samples. These improvements consisted of forcing the incoming ozonized air to mix with the chamber air before it came in contact with the samples, and of disrupting the incoming airflow with baffles to even out the airflow across the samples. Samples in the MAST/Lunaire chamber are laid flat across shelves. To test the uniformity, samples were placed near the air inlet, the air outlet, and in the middle of the test chamber shelves. Table 3 shows the percent deviation between the maximum and minimum patch fading for each sample location. The data confirms that that the greatest variation in fade rates was observed near the sample inlet.

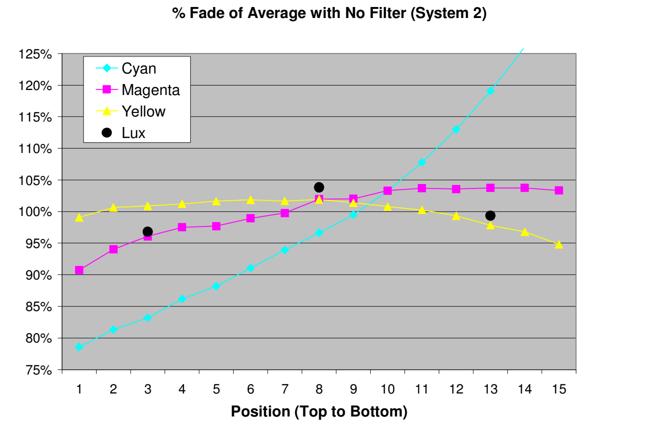

Figure 5. Percent of the total average fade for each color patch of System 2 in Ci3000 with airflow across sample.

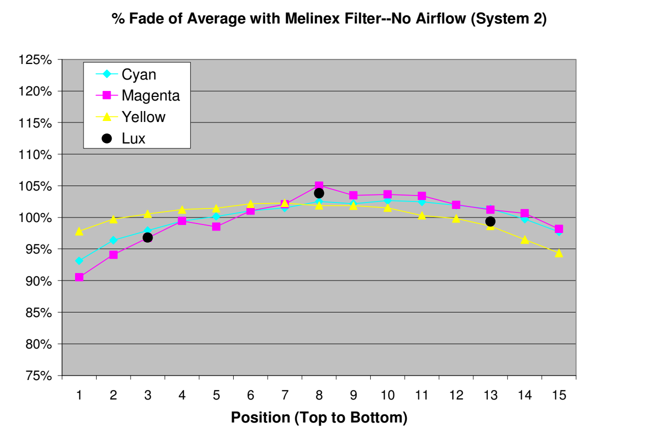

Figure 6. Percent of the total average fade for each color patch of System 2 in Ci3000 with no airflow across sample.

Table 3. Percent deviation of fade in MAST/Lunaire ozone chamber based on sample location.

	% Deviation (Max - Min)		
System 1	Cyan	Magenta	Yellow
Inlet	1.5%	1.0%	1.2%
Outlet	1.2%	0.6%	1.0%
Middle	1.3%	0.6%	0.7%

System 2	Cyan	Magenta	Yellow
Inlet	2.8%	2.8%	3.7%
Outlet	1.7%	2.2%	1.4%
Middle	1.6%	2.3%	1.6%

System 3	Cyan	Magenta	Yellow
Inlet	7.9%	6.6%	6.2%
Outlet	6.4%	3.3%	2.4%
Middle	6.9%	4.5%	2.2%

The last piece of test equipment evaluated was the Hampden 903 ozone chamber. This device has a carousel that moves samples within the chamber, thus smoothing out any local environmental variations that each sample experiences. However, the movement only occurs in two dimensions, with no movement taking place in the dimension parallel to the incoming airflow. Therefore, each patch on a test target remains at a fixed distance from the incoming airflow. For this test, samples were mounted facing outward and inward on the carousel: the only difference is that outward facing samples receive some additional airflow as they pass a fan mounted in the chamber. Table 4 shows the percent deviation between the maximum and minimum patch fading for each sample location.

Table 4. Percent deviation of fade in Hampden 903 ozone chamber based on sample location.

	% Deviation (Max - Min)		
System 1	**Cyan**	**Magenta**	**Yellow**
Outside	2.4%	0.6%	0.8%
Inside	2.3%	0.8%	1.3%

System 2	**Cyan**	**Magenta**	**Yellow**
Outside	1.8%	2.1%	1.4%
Inside	1.5%	1.8%	2.0%

System 3	**Cyan**	**Magenta**	**Yellow**
Outside	8.7%	3.7%	1.8%
Inside	7.1%	3.6%	2.9%

Once again system 3 is showing the greatest deviation, suggesting that the variation seen in the other ozone chamber was not due to local differences in airflow. This was confirmed by closely examining the behavior of individual patches as shown in Figure 7: there is no trend that can be attributed to airflow or any physical aspect of the chamber's design. The investigation then switched to focus on the printer itself, and specifically the variation observed in the initial patch densities. These densities should have been identical—as the print file instructed the printer to print the same patch repeatedly—but in reality the density was not uniformly printed. By dividing each patch's density measurement with the average density measurement for all patches of that color, the resulting plot as shown in Figure 8 was found to closely resemble Figure 7. Subsequently dividing the percent fade of average by a scaled percent density of average resulted in the plot shown in Figure 9. Another way to understand this is that patches with higher initial density faded faster than patches with lower initial density. Lack of familiarity with the printer in question prevents further explanation as to why this was happening. But it is of concern that the fade rates tracked the density so closely.

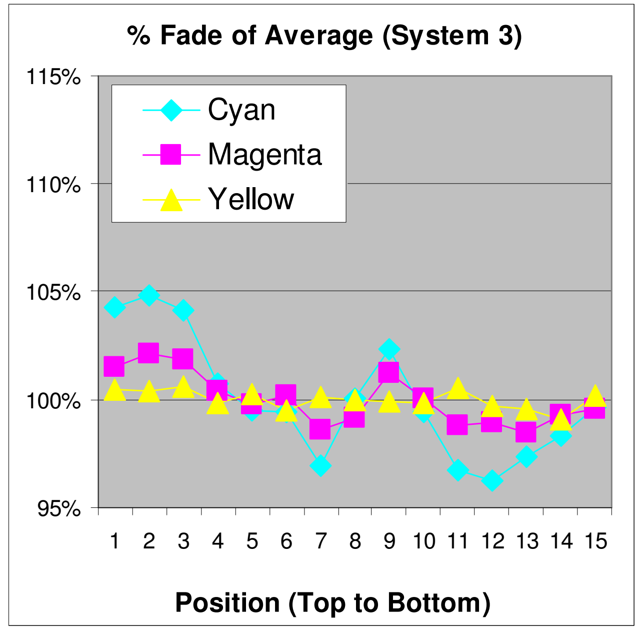

Figure 7. Percent of the total average fade for each color patch of System 3 in Hampden 903 ozone chamber (facing outward).

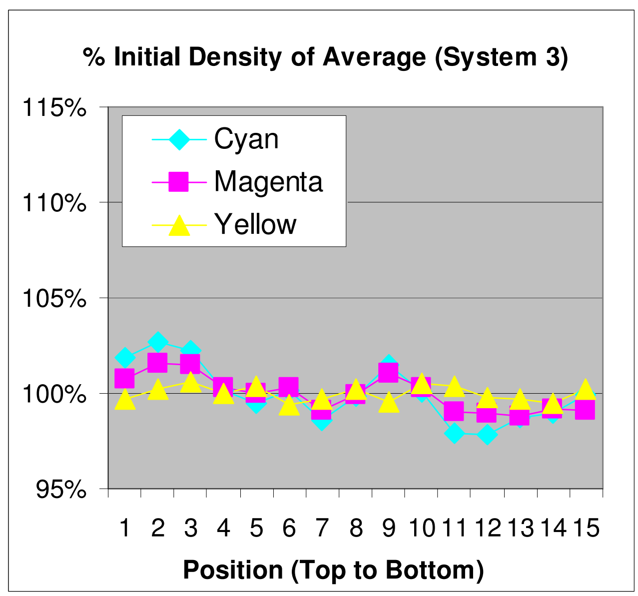

Figure 8. Percent of the total average initial density for each color patch of System 3 in Hampden 903 ozone chamber (facing outward).

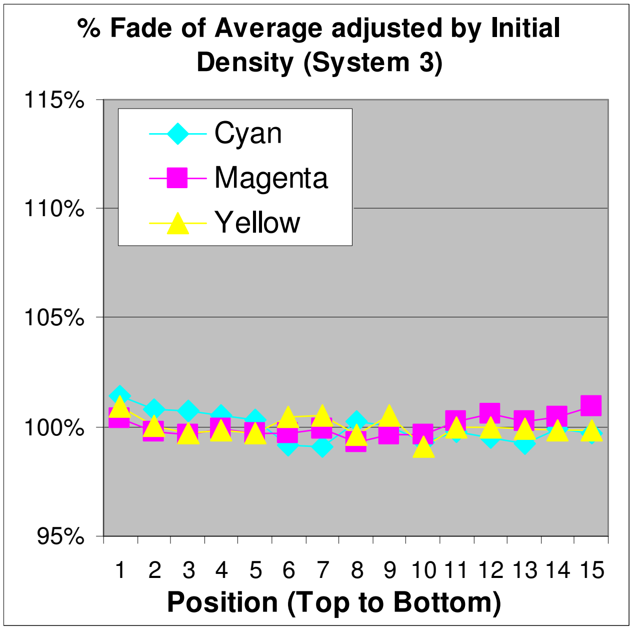

Figure 9. Percent of the total average fade divided by each patch's normalized density for each color patch of System 3 in Hampden 903 ozone chamber.

Conclusion

It has been shown that samples are not fading uniformly in several image permanence test devices, especially in Xenon light stability test chambers. The primary factors involve the physical design of the chamber: the variation in light intensity at the sample, and the influence of airflow contribute to the non-uniform fade behaviors. Eliminating airflow in the Xenon light test resulted in much better fade uniformity. And it is a key focus of ongoing testing which will explore different designs of the sample test bracket.

Although the variation in light intensity between samples was greater in the Ci4000 than in the Ci3000, the fade variation within a given sample was smaller. This is because the samples are further from the Xenon lamp in the Ci4000. By continuing to increase the distance between the lamp and the samples, it is possible to achieve excellent uniformity and this will be the subject of future investigation by using a larger Ci5000 Xenon test chamber.

Investigation into ozone test chambers found that two different design approaches both performed better than expected. Typical percent deviation between test targets based on location was about 1-3%. The only system found to exhibit greater variation had printed the test target's color patches with irregular densities. The variation in these densities matched the variation in fade rate for that system, thus confirming that the test chamber was not responsible, but raised additional concerns that the print system itself may be a substantial contributor to variation in image permanence testing.

This research points out the need for each laboratory to fully characterize the equipment used in their image permanence testing by performing experiments specially designed to evaluate consistency and uniformity.

Author Biographies

Matthew Comstock received his B.S and M.S. degrees from Purdue University in Mechanical Engineering specializing in heat transfer and thermodynamics. He joined Lexmark International, Inc. in 1999 as a development engineer for color laser products. Since 2005 he has been responsible for the Lexmark Image Permanence Lab in Lexington, KY. His work is primarily focused on image permanence test method development and image permanence testing.

Ann McCarthy is an Imaging Systems Architect with Lexmark International, Inc., in Lexington, KY. She received her BS (1982) in Computer Engineering and MS (1997) in Imaging Science from the Rochester Institute of Technology. Ms. McCarthy has been active in the imaging and printing industry for over 25 years, including seventeen years with Eastman Kodak Co., five years with Xerox Corporation, and over five years with Lexmark International, Inc., with contributions in color image and print path development, color data encoding, imaging interoperability across distributed workflows, and work on related international standards, including IEC ISO JTC1 SC28, CIE Div 8, ISO TC 42, ECMA TC46, and the International Color Consortium (ICC). Her publications include IS&T tutorials on color management, ICC white papers, and ISCC, SPIE and IS&T conference presentations.