Reproducibility Between Xenon Test Chambers in Different Laboratories

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Abstract

An important foundation of standardized testing is that multiple test laboratories are able to reproduce results following the standardized test method. In prior research it was found that, when testing for the light stability of printed materials, two Xenon test chambers located in different laboratories following the same test procedure were not able to provide consistent inkjet print image fade results. Continuing investigation has shown that airflow and air quality were responsible for the discrepancy.

Introduction

Xenon light is often used for evaluating the durability of inkjet print samples because of its good spectral approximation to sunlight. Earlier investigation into the sources of variation in Xenon testing found that temperature had a significant impact on the sample fade rate [1]. However, there were other sources of variation not controlled in that testing. When running the same sample set at identical sample temperature and percent relative humidity in two Xenon test chambers, the results did not match. Table 1 is reproduced from that earlier study. It compares the fade rates of the inkjet colorants between the Xenon test chambers—Atlas Ci4000 and Atlas Ci3000 Weather-Ometers. For example, if the fade rate of sample A1 Cyan had been 20% optical density loss in the Ci4000 and 40% in the Ci3000, then the comparative fade rate would be 50% (i.e. the sample faded 50% as much in the Ci4000 as it did in the Ci3000 for the same cumulative light exposure). Samples shaded in gray represent pigment ink systems (B1, C1, and E2), while the others are dye inks. All samples were printed on porous photo papers.

Table 1. Sample fade in Ci4000 compared to Ci3000 at 35C.

	Comparative Fade Rate at Consistent Time Ci4000 vs. Ci3000 at 35C		
ID	**Cyan**	**Magenta**	**Yellow**
A1	49%	68%	49%
B1	23%	52%	103%
C1	25%	50%	99%
D1	67%	87%	70%
E2	36%	101%	106%
F2	62%	91%	75%
G2	67%	101%	92%
H3	53%	88%	110%
J4	43%	88%	72%
K5	39%	85%	99%

The results from the earlier investigation showed that in nearly all cases, the samples faded less in the Ci4000 than in the Ci3000. It was also observed that the Ci4000 had been moved to a specially built lab with large activated carbon filters, while the Ci3000 remained in a lab with unfiltered air. Furthermore, another Xenon test evaluating sample fade uniformity based on patch position within the Ci3000 test chamber had used a polyester film, Melinex®, to successfully isolate the sample from airflow and achieve more uniform results [2]. Consequently, it was theorized that the difference in air quality was responsible for the discrepancy in test results between the two laboratories.

Experimental Results and Discussion

Based on previous testing, a new experiment was designed to compare sample fading while eliminating airflow as a variable. The same Ci4000 and Ci3000 instruments were used again with all aspects of the test run at identical conditions as before, except this time all the samples were covered with Melinex®. The comparative results are shown in Table 2.

Table 2. Sample fade in Ci4000 compared to Ci3000 at 35C with airflow eliminated using Melinex®.

	Comparative Fade Rate at Consistent Time Ci4000 vs. Ci3000 at 35C (Melinex®)		
ID	**Cyan**	**Magenta**	**Yellow**
A1	102%	104%	101%
B1	NA	NA	84%
C1	103%	74%	84%
D1	102%	97%	100%
E2	92%	100%	94%
F2	101%	92%	92%
G2	98%	95%	90%
H3	87%	93%	97%
J4	99%	91%	101%
K5	97%	98%	89%

The elimination of airflow dramatically improved the consistency in test results between the two Xenon test chambers. System B1 Cyan and Magenta patches had insufficient fading at the end of the test for accurate comparisons to be made. The largest deviation, System C1 Magenta, was comparing 4.5% fade in the Ci4000 with 6.1% fade in the Ci3000, an absolute difference of only 1.6% density loss.

To verify these results another experiment was devised with three inkjet systems mounted in one of three different ways and tested in both the Ci4000 and Ci3000. The first mounting method once again used Melinex® directly on the sample to block the airflow. The second method placed the Melinex® above the sample with a 10mm air gap, allowing some airflow across the sample. And the third mounting method placed a shield above the sample to block the light, while allowing airflow, thus providing a good measure of the amount of "air fade" occurring. Test conditions were the same as in the previous experiments.

Table 3 shows a comparison between the no airflow and airflow mounting conditions. Once again, the samples with no airflow had close agreement between the two test chambers, but those with airflow did not have matching fade results. Systems A and B were dye inks while System C was a pigment ink.

Table 3. Sample fade in Ci4000 compared to Ci3000 at 35C in second experiment comparing influence of airflow.

		Comparative Fade Rate at Consistent Time Ci4000 vs. Ci3000 at 35C (Melinex®)		
Mount	**System**	**Cyan**	**Magenta**	**Yellow**
No Airflow	**A**	101%	96%	103%
	B	94%	98%	103%
	C	92%	94%	90%
With Airflow	**A**	28%	49%	54%
	B	20%	70%	68%
	C	24%	89%	74%

Table 4 shows the optical density loss for the cyan colorants of the three systems tested in each of the three mounting conditions. The increase in fading in light with airflow compared to no airflow is greater than due to air fading alone, suggesting an interaction. This relationship held with both unfiltered and filtered air, although the air fade with filtered air was much less.

Table 4. Cyan patch sample fade in Ci3000 and Ci4000 at 35C comparing three different mounting conditions: light with no airflow, light with airflow, and no light with airflow.

	Cyan	**% OD Change**	
Mount	**System**	**Ci3000**	**Ci4000**
Light with No Airflow	**A**	-17.0%	-17.2%
	B	-8.8%	-8.3%
	C	-6.8%	-6.3%
Light With Airflow	**A**	-83.3%	-23.4%
	B	-63.9%	-12.5%
	C	-14.4%	-3.4%
No Light With Airflow	**A**	-52.0%	-2.7%
	B	-23.7%	-1.5%
	C	-3.9%	-0.2%

Table 5 displays the test results for the magenta colorants, and Table 6 the yellow colorants. The trends are shown to be the same for cyan, magenta and yellow colorants, despite the noise contributed by the higher sensitivity to humidity migration of the magenta and yellow dyes. Moreover, recent studies have found that even with a 10mm air gap, the airflow on the sample is restricted enough to allow sample heating of several degrees compared to unobstructed airflow. This also decreases the local relative humidity, which further influences the sample fade rate and will be a topic of a future paper. The samples directly in contact with Melinex® achieved the desired sample temperature because the thin film conducted more heat away from the sample than when the Melinex® was placed above the sample with an air gap. In the Ci4000 testing, there may be additional unidentified variables which contributed to less fading for the yellow dyes in airflow as compared to the no airflow test case.

Table 5. Magenta patch sample fade in Ci3000 and Ci4000 at 35C comparing three different mounting conditions: light with no airflow, light with airflow, and no light with airflow.

	Magenta	**% OD Change**	
Mount	**System**	**Ci3000**	**Ci4000**
Light with No Airflow	**A**	-32.6%	-31.2%
	B	-32.8%	-32.0%
	C	-6.5%	-6.1%
Light With Airflow	**A**	-52.0%	-25.4%
	B	-45.7%	-32.1%
	C	-6.8%	-6.1%
No Light With Airflow	**A**	-31.0%	-0.7%
	B	-8.5%	-1.3%
	C	-2.5%	-1.3%

Table 6. Yellow patch sample fade in Ci3000 and Ci4000 at 35C comparing three different mounting conditions: light with no airflow, light with airflow, and no light with airflow.

	Yellow	**% OD Change**	
Mount	**System**	**Ci3000**	**Ci4000**
Light with No Airflow	**A**	-33.7%	-34.8%
	B	-29.9%	-30.8%
	C	-6.7%	-6.0%
Light With Airflow	**A**	-46.2%	-25.1%
	B	-38.3%	-26.1%
	C	-8.5%	-6.3%
No Light With Airflow	**A**	-7.8%	-2.0%
	B	-8.5%	-3.9%
	C	-1.7%	-0.6%

In 2010 Lexmark purchased an Atlas Ci5000 Weather-Ometer which was placed in the same room as the Ci4000. A series of experiments were performed with both chambers set at the same operating conditions. Table 7 shows results from one of these tests evaluating 3 different print systems, all dye inks on porous photo paper. Despite using filtered air and adjusting the machine setpoints such that the sample conditions were as close as possible, only 3 out of the 9 fade rates matched.

Table 7. Comparing Xenon Ci5000 with Ci4000 at identical operating conditions with airflow.

		% OD Change		% Deviation
System	**Color**	**Ci5000**	**Ci4000**	**Ci5000 vs Ci4000**
1	**Cyan**	-21.5%	-15.9%	**36%**
	Magenta	-44.5%	-43.4%	**2%**
	Yellow	-20.9%	-28.9%	**-28%**
2	**Cyan**	-18.2%	-13.1%	**39%**
	Magenta	-11.2%	-11.1%	**1%**
	Yellow	-12.7%	-15.5%	**-18%**
3	**Cyan**	-13.8%	-6.8%	**101%**
	Magenta	-19.1%	-27.4%	**-30%**
	Yellow	-12.3%	-11.4%	**8%**

In the same experiment the sample replicates were covered with Melinex® to eliminate airflow. Those results are shown in Table 8, with 7 of the 9 samples matching.

Table 8. Comparing Xenon Ci5000 with Ci4000 at identical operating conditions with no airflow (test samples covered with Melinex®).

		% OD Change	
System	Color	Ci5000	Ci4000
1	Cyan	-5.8%	-6.9%
	Magenta	-24.1%	-26.6%
	Yellow	-20.8%	-26.2%
2	Cyan	-9.9%	-10.6%
	Magenta	-5.7%	-6.6%
	Yellow	-11.3%	-15.8%
3	Cyan	-3.8%	-3.1%
	Magenta	-18.8%	-18.8%
	Yellow	-9.5%	-10.8%

After further detailed measurement of the Xenon chambers, it was discovered that the average airflow on the test samples in the Ci5000 was about 3 m/s (meters per second), while in the Ci4000 it was less than 1 m/s. The higher airflow also allowed the air temperature of the Ci5000 to be closer to the sample temperature, about 22.5C air temperature at 25C sample temperature. The Ci4000 required a lower air temperature of 20C to keep the sample temperature cooled to 25C. An air temperature closer to the sample temperature is desirable.

The air guides in the Ci4000 were modified to improve the airflow rate, and these adjustments are still a work in progress. The Ci4000 is now able to reach airflows greater than 1 m/s, yet still not as high as the Ci5000. At the time this paper is being written another test is underway to evaluate whether increasing the airflow in the Ci4000 and decreasing the airflow in the Ci5000 are able to bring the two chambers into closer agreement.

With the addition of the Ci5000 to the Lexmark image permanence lab, the smaller Ci4000 became available for exploratory research into the factors that influence Xenon test results. As shown in Figure 1, a temporary modification was made to the Ci4000 by installing air ducts to bring in building air from outside the lab. This air was conditioned by the building HVAC system, but was not specially filtered to remove ozone and other contaminants. The ozone level in the lab fluctuates between 0 and 2 ppb (parts per billion), with a long term average near 0.6 ppb. Figure 2 shows ozone measurements during a typical Xenon test cycle with filtered lab air. The ozone level in the building outside the lab fluctuates between 0 and 25 ppb with an average of just above 10 ppb from April to October. Ozone measurements of Xenon testing with unfiltered air are shown in Figure 3.

A test with 13 inkjet print samples was evaluated with filtered and unfiltered air using the Ci5000 and modified Ci4000. 6 of the inks were pigments, while the remaining 7 were dyes. Samples were mounted both with and without airflow. Only 7 out of the possible 39 cyan, magenta, yellow system colorants in airflow matched—while 35 out of 39 system colorants matched when airflow was eliminated. Table 9 shows some of the system results of the cyan colorants in these tests. Systems 3, 5, and 6 are pigment inks.

Figure 1. Atlas Ci4000 Weather-Ometer with air intake modified to bring in unfiltered air from the building rather than using filtered lab air.

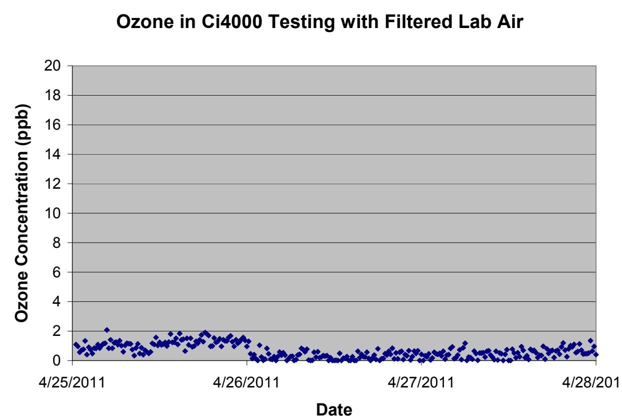

Figure 2. Ozone level in Atlas Ci4000 Weather-Ometer with filtered air.

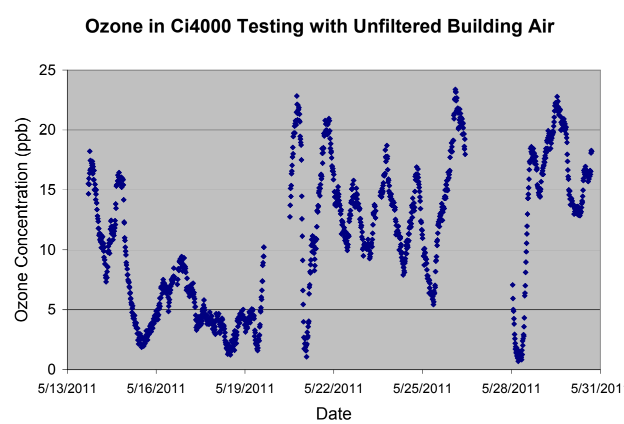

Figure 3. Ozone level in Atlas Ci4000 Weather-Ometer with modified air intake using unfiltered building air. Weather was cool and cloudy at the beginning of these measurements, and hot and sunny at the end of testing.

Table 9. Excerpt of cyan ink results in test comparing no airflow with airflow in Xenon Ci4000 (unfiltered air) and Ci5000 (filtered air).

		Cyan % OD Change	
System	**Airflow**	**Ci4000**	**Ci5000**
1	No	-16.6%	-17.2%
	Yes	-76.5%	-40.9%
2	No	-7.4%	-7.2%
	Yes	-68.7%	-23.4%
3	No	-2.4%	-2.0%
	Yes	-7.9%	-2.2%
4	No	-13.8%	-13.4%
	Yes	-74.7%	-46.7%
5	No	-2.9%	-2.8%
	Yes	-5.0%	-2.2%
6	No	-6.4%	-6.9%
	Yes	-12.5%	-6.4%
7	No	-11.8%	-11.5%
	Yes	-84.1%	-48.4%
8	No	-6.4%	-6.5%
	Yes	-71.9%	-25.1%

Further experiments have been performed which explore the influence of airflow and air quality on sample fading. Many of these were designed to evaluate the uniformity of sample fade based on position within the Xenon test chamber and will be discussed in detail in a future paper. The results confirm that the variation of fade rate for individual color test patches corresponds to the variation in airflow within the test chamber, especially when using unfiltered air and placing a glass filter near the sample. For colorants which are sensitive to air fading, it is possible for a color patch near the edge of a test target to fade nearly twice as much as a color patch near the center of the test target less than 10cm away.

Conclusion

This paper could easily have been titled "Influence of Airflow on Xenon Testing". Achieving consistent results between two Xenon chambers, whether located in the same laboratory or different laboratories has proven to be elusive. Differences in air quality between two labs can easily affect Xenon test results of inkjet print samples, and this includes pigment inks. Moreover, each Xenon test chamber model, whether from the same company or different companies, may have different airflow rates which can also influence how print samples fade. Yet there is evidence that by controlling airflow along with air quality, sample temperature, and air relative humidity, a standardized test method can achieve reproducible results among different laboratories and equipment.

The authors do not recommend that Melinex® be used for standardized Xenon testing, as it is susceptible to solarization and also visibly yellows with exposure. However, some other method of eliminating airflow on the sample may be an easier solution than specifying the allowable airflow on each test sample in a Xenon chamber. Print images displayed in homes are often framed behind glass and thus experience negligible airflow. It would be reasonable to specify an accelerated light stability test referenced to match this home use condition. Unfortunately, the authors' first prototype fixture simulating a picture frame in Xenon testing was only marginally successful. The frame was not sealed tightly enough, allowing some air leakage, and the fixture acted as a miniature greenhouse, raising the sample temperature by several degrees. Moreover, there was a temperature gradient on the sample, with the center at a higher temperature than the edges.

Historically, many light test methods have focused on specifying the light source, light intensity, spectral filtering, and lamp and filter aging. However, testing has shown that small variations in airflow, air quality, sample temperature, and relative humidity can have a much larger impact on print sample fade results. As a result, specifications for standardized light stability testing must emphasize control of these test characteristics. Future testing will broaden the range of digital print technologies evaluated in this research and continue to isolate and prioritize factors that affect the test results.

References

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Author Biography

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 six 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.