# Influence of Temperature in Xenon Testing

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## Abstract

*The digital print industry is working toward the goal of adopting improved test methods for image permanence. As part of this effort, the new test methods are being designed to isolate the environmental variables that impact image permanence. The benefits of this approach are that it simplifies the test methods and test equipment while promoting test results that can be reproduced at other test laboratories. To understand which variables to isolate for a given test method, it is necessary to investigate a broad range of conditions which may affect the test results. This study focused on the impact of changing the temperature in Xenon testing while holding all other conditions constant. It was found that higher temperatures significantly increased the sample fade rate and that this test parameter will need to be tightly controlled. This research is part of ongoing work contributing to the development of standardized test methods for image permanence.*


## Introduction

Xenon light sources are often used to simulate sunlight for testing durability of many products. Like sunlight, the infrared component of Xenon light can heat test samples well above the ambient air temperature of the test chamber. Consequently, some Xenon test chambers are equipped with refrigeration systems designed to help keep test samples cool. At the time of this testing, Lexmark had two Xenon test chambers, one capable of active refrigeration and one lacking that capability. Earlier work had found that both temperature and humidity play an important role in the image permanence of print samples in ozone stability testing [1]. The research described in this paper investigates the relevance of sample temperature to the stability of print images in Xenon light testing.

## Experiment

The following equipment was used in testing:

- Minolta T-10M Illuminance Meter
- Kahn Optidew Bench chilled mirror hygrometer
- Digi-Sense 12-Channel Scanning Thermocouple Thermometer Model 69200 with Type T Thermocouples
- Atlas Ci4000 Xenon Weather-Ometer
- Atlas Ci3000 Xenon Weather-Ometer
- Gretag Spectrolino/Spectroscan

The Atlas Xenon Weather-Ometers can be fitted with different glass filters on the lamp to customize the spectral power distribution of the emitted light. For this testing, lamps in both chambers had soda lime outer filters and CIRA (Coated Infrared Absorbing) inner filters. These test chambers were also originally equipped with black panel temperature (BPT) sensors, used to maintain sample temperature control in the chamber. Prior to beginning this study the sensors were replaced with white panel temperature (WPT) sensors that much more closely match the actual sample temperature, as shown in Table 1. This paper will hereafter refer to the WPT as the sample temperature, although it is understood that the actual sample temperatures deviate from the WPT depending on ink colorants, patch density, patch size, and several other important control variables such as airflow rate and light intensity.

**Table 1. Xenon sample temperatures: relative to air temperature (at 80klux and 2 m/s airflow rate).**

| Temperature [Celsius] (Relative to Air) | |
|---|---|
| Black Patch | 8.6 |
| Gray Patch | 4.8 |
| Cyan Patch | 6.7 |
| Magenta Patch | 5.7 |
| Yellow Patch | 5.9 |
| Unprinted Media | 4.9 |
| Black Panel | 15.4 |
| White Panel | 5.1 |

Each Xenon test chamber design and setup has an inherent range of capability for stable operation and control at the sample locations, as a result of refrigeration control (if present), light intensity operating point, SPD filtration, airflow control and automated process control logic.

The light intensity was set to control at 80 klux (+/-3 klux) for all tests using an independent light meter. At this desired light intensity, the lowest stable operating temperature for the Atlas Ci3000 was found to be at a 28C air temperature and 35C sample temperature. This became the point of comparison to the Ci4000's standard operating condition of 20C air temperature and 25C sample temperature. The Ci4000 was run at both sample temperatures while the Ci3000 was only run at the higher temperature. Having a common test temperature for both chambers permitted an analysis of the reproducibility between them. All testing was at 50% RH. Temperature and relative humidity in both chambers were referenced to the same chilled mirror hygrometer, which was also equipped with a Resistance Temperature Detector (RTD).

Test samples were evaluated from 12 different systems, although only 10 of these could be tested in the Ci3000 due to its smaller size. Inks will be identified by the letters A through P and media by the numbers 1 through 5. Pigment and dye based inks were printed on porous photo papers recommended by their respective manufacturers. The tests were each run for a total of 420 hours, with measurements made every 70 hours.

## Results and Discussion

The first part of the study investigated only the influence of temperature in the Xenon light stability test. This was accomplished by testing samples in the Ci4000 at 25C with refrigeration active (20C air), and then upon completion of that test the refrigeration was turned off and the sample temperature setpoint changed to 35C (28C air) for a follow on test. The samples were prepared separately for these tests so that each had a 2-week dry time prior to testing [2].

Turning the refrigeration system on and off revealed an environmental control problem in the Ci4000: the refrigeration system is overpowered for image permanence test conditions. A consequence of this is that the humidity fluctuates more when the refrigeration is on, as shown in Figure 1, than when it is off, as shown in Figure 2. The temperature control is about the same for both modes of operation, unless the refrigeration coils ice up, which does happen on occasion.

The preferred mode of operating the Ci4000 is with the refrigeration off, as it provides more stability in the environmental control. Several modifications have been made to the Ci4000 to allow it to run more tests without refrigeration. The most promising is simply using chilled water instead of refrigerant within the chamber's evaporator coils to cool the air within the chamber.

Once the tests at both temperatures were complete, fade data from each of the 12 systems were compared at consistent times between the two temperatures. The data for all systems and primary colorants are shown in Table 2. For example, system A1 cyan faded 70% as much at 25C as it did at 35C, while system A1 yellow faded the same at 25C and 35C. The actual fade rates of these systems is not shown, but varied considerably. System C1 cyan fade at 420 hours was 6.2% at 25C and 9.3% at 35C, while system D1 fade at 350 hours was 33.7% at 25C and 58.2% at 35C. The data used in the calculations was selected from the point in time at which the sample fade was closest to 40% for both test temperatures. The four systems shown with grayed cells are those using pigment inks. The cyan ink for M5 did not fade enough to provide an accurate comparison.

Among all the inks tested, none faded more at 25C than at 35C, although there were a few that showed equivalent fade at the two temperatures (values near 100% in Table 2). Humidity may have played a role in this outcome; for example, it is known that the yellow ink of system A1 is sensitive to humidity. Even though relative humidity with respect to air temperature was kept constant at 50%, the absolute moisture content of the sample at 35C was greater than at 25C and could have led to ink migration. Ink migration can cause an increase in optical density, which would thus counteract the increased fading at 35C and make it appear as though there was no difference between the two temperatures. Future tests are planned to isolate these interactions. The pigment inks, which are not sensitive to humidity migration, all showed much less fading at 25C than at 35C.

After concluding the 35C temperature test in the Ci4000, the same test was run in the Ci3000 to determine if the test was reproducible. Reference measurement instruments were used to ensure that the environment and illumination were identical. The results are shown in Table 3 using the same method of comparing systems as described earlier. It was found that in a majority of cases the samples in the Ci3000 faded faster than in the Ci4000. For example, system A1 cyan faded 50% as much in the Ci4000 as in the Ci3000 when compared at equivalent test times, sample temperature, light intensity, %RH, and so forth.

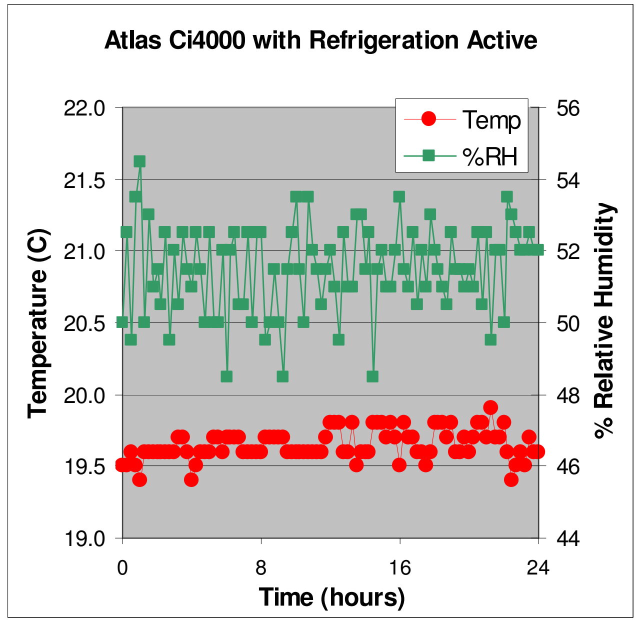


*Figure 1. Air temperature and %RH measurements during test in Ci4000 with refrigeration active.*

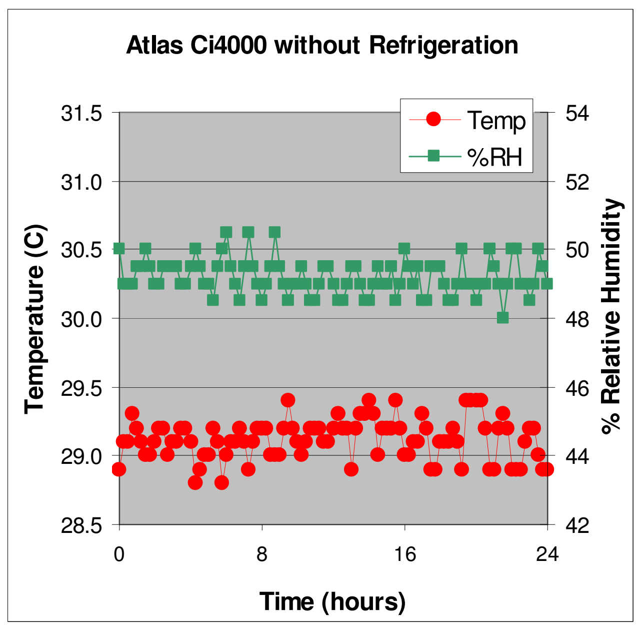


*Figure 2. Air temperature and %RH measurements during test in Ci4000 with refrigeration turned off (using chilled water instead).*

There is a critical piece of information that has thus far been omitted in the test description that explains this shocking discrepancy: the Ci4000 is located in an environmentally controlled lab with extensive air filtering; the Ci3000 is not. Table 4 shows fade data from experiments of these same systems after only 25 PPM-hours of ozone exposure. And ozone is just one of several possible air contaminants that may have influenced the results in the Ci3000. The tests described in this paper were conducted in the summer of 2009. A follow up test in the Ci3000 during the winter of 2010 repeated the results seen earlier. And since ozone levels are lower in the winter than the summer, it suggests that other air contaminants are involved.

## Conclusion

Environmental control is a key component to repeatable and reproducible test results in Xenon light stability testing for image permanence. Just a 10C increase in sample temperature resulted in large increases in fade rates for many types of inkjet print samples.

Moreover, maintaining air quality was found to be another key requirement in Xenon light stability testing. Using unfiltered air confounds test results by compounding multiple fade mechanisms. Recent follow-up testing has confirmed that by eliminating airflow and its potential contaminants it is possible to reconcile the test data between Xenon test chambers located in different labs—one with filtered air, one with unfiltered air. The details of that study will be the topic of a future paper.

Lexmark is acquiring a larger Atlas Ci5000 Xenon Weather-Ometer in the summer of 2010, thus freeing the Ci4000 for additional exploratory research into the impact of environment on print sample longevity.

## References


[1] M. Comstock, A. McCarthy, "Effect of Temperature and Humidity on Rate of Image Fading in Ozone", Final Program and Proceedings of IS&T's NIP24: International Conference on Digital Printing Technologies, Pittsburgh, PA, pp. 237-241 (2008).

[2] M. Comstock, A. McCarthy, "Effect of Dry Time on Rate of Image Change in Xenon, Ozone, and Humidity Tests", Final Program and Proceedings of IS&T's NIP24: International Conference on Digital Printing Technologies, Pittsburgh, PA, pp. 219-224 (2008).


## 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.*


**Table 2. Sample fade rate at 25C compared to 35C in Ci4000.**

| | Comparative Fade Rate at Consistent Time Ci4000: 25C vs. 35C | | |
|---|---|---|---|
| ID | Cyan | Magenta | Yellow |
| A1 | 70% | 82% | 101% |
| B1 | 59% | 59% | 42% |
| C1 | 66% | 68% | 56% |
| D1 | 58% | 86% | 89% |
| E2 | 68% | 84% | 77% |
| F2 | 79% | 65% | 68% |
| G2 | 69% | 71% | 71% |
| H3 | 71% | 68% | 81% |
| J4 | 76% | 98% | 75% |
| K5 | 52% | 66% | 88% |
| M5 | NA | 71% | 61% |
| P4 | 77% | 92% | 90% |

**Table 3. 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% |

**Table 4. Sample fade after 25 PPM-hours ozone exposure.**

| | Ozone Sensitivity % Fade at 25 PPM-hours | | |
|---|---|---|---|
| ID | Cyan | Magenta | Yellow |
| A1 | 41.2% | 36.0% | 7.6% |
| B1 | 3.2% | 1.9% | 1.1% |
| C1 | 6.6% | 4.5% | 1.1% |
| D1 | 22.7% | 10.7% | 7.3% |
| E2 | 3.1% | 1.7% | 1.0% |
| F2 | 40.3% | 48.1% | 11.7% |
| G2 | 6.7% | 1.9% | 2.2% |
| H3 | 8.9% | 2.5% | 2.0% |
| J4 | 10.7% | 3.0% | 12.8% |
| K5 | 2.0% | 1.6% | 1.0% |