# Test of Inkjet Prints

## For

## Eastman Kodak Company

March 2007

Completed By


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# 1.0 Executive Summary

Eastman Kodak Company asked Torrey Pines Research (TPR) to conduct an image stability test on a number of inkjet print samples. Kodak defined the test plan and conditions, and numbered print samples were supplied to TPR already printed. No further information was provided about the prints. The test was therefore a blind test.

Following the completion of the test, Kodak disclosed the identity of the numbered prints by providing a list of the printers, inks and media used to make each print.

The test images were made from ten different commercially available inkjet printers, each using the manufacturer recommended ink set. Each printer was used to print images on the manufacturer recommended media and also on new Kodak inkjet media. In addition, images were printed using the not-yet-released Kodak inkjet printer that has since been launched as the Kodak Easy Share 5000 series.

An image consisting of a number of color patches was used for most of the print samples (Appendix A.). Print samples supplied were exposed to three separate accelerated tests comprising 50 kLux fluorescent light exposure with polycarbonate filtration, 80% humidity with no light, and 1 part per million ozone with no light. At periodic intervals up to 224 days total exposure, TPR measured the colorimetric values of each of 57 color patches on each print sample including the media background. In addition to the color patch image, an image that included bleed patterns and a photo was used for the humidity test (Appendix B).

TPR used two main criteria for assessing the stability performance of the prints using composite colorimetric values. The first of these two values is intended to represent the point where most people would be able to detect a color change in their print. This value is established by a consensus rather than a standard. The second value is intended to represent the point where most people would find the extent of the color change to be unacceptable, and is based on illustrations provided in an ISO standard. TPR then used these criteria to compare the relative stability of the prints. No attempt has been made to project likely life in years. In addition to the colorimetric measurements, TPR used observers to make subjective visual assessments of the second image used in the humidity test.

The results from the light fade test are shown in Figure 1. The relative color fade for each color is depicted in that color and the total color fade is represented by the height of the bar. The left axis shows 4 levels that are judged to be 1 = minimal or no change, 2 = slight change, 3 = noticeable change and 4 = unacceptable change.

None of the print samples in the high humidity test reached the level of color change that would be unacceptable to most observers. Discernable changes were visible when visually examining the prints for intercolor bleed and edge acuity however. These changes were assessed using a similar 1 through 4 grading and the results of this visual assessment are depicted in Figure 2.

The ozone exposure test had the most dramatic effect on the group of samples. Only one print sample, the HP8250, survived the ozone exposure test to 112 days without reaching the point of unacceptable color change. This test was terminated at 112 days for this reason. These results were normalized for a 1 through 4 grading scheme similar to the other result and are shown in Figure 3 below.

At the conclusion of the test all the print samples were returned to Kodak.

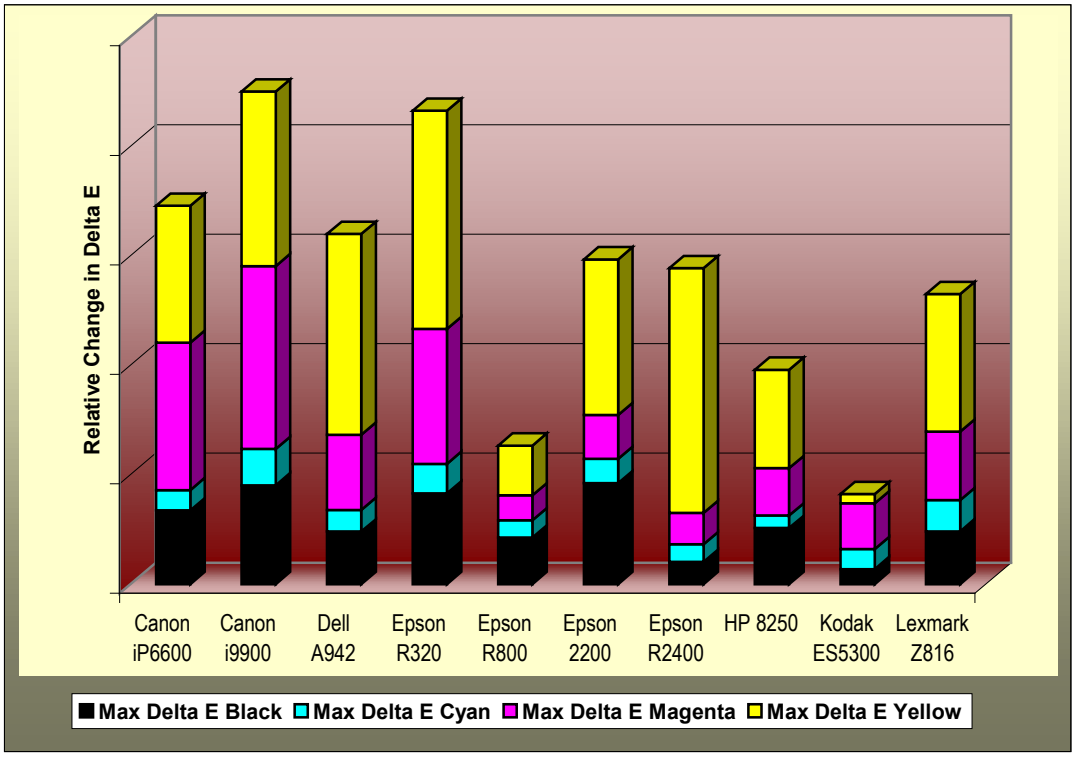


**Figure 1 - Summary of 50kLux Light Fade Performance - Lower is Better**

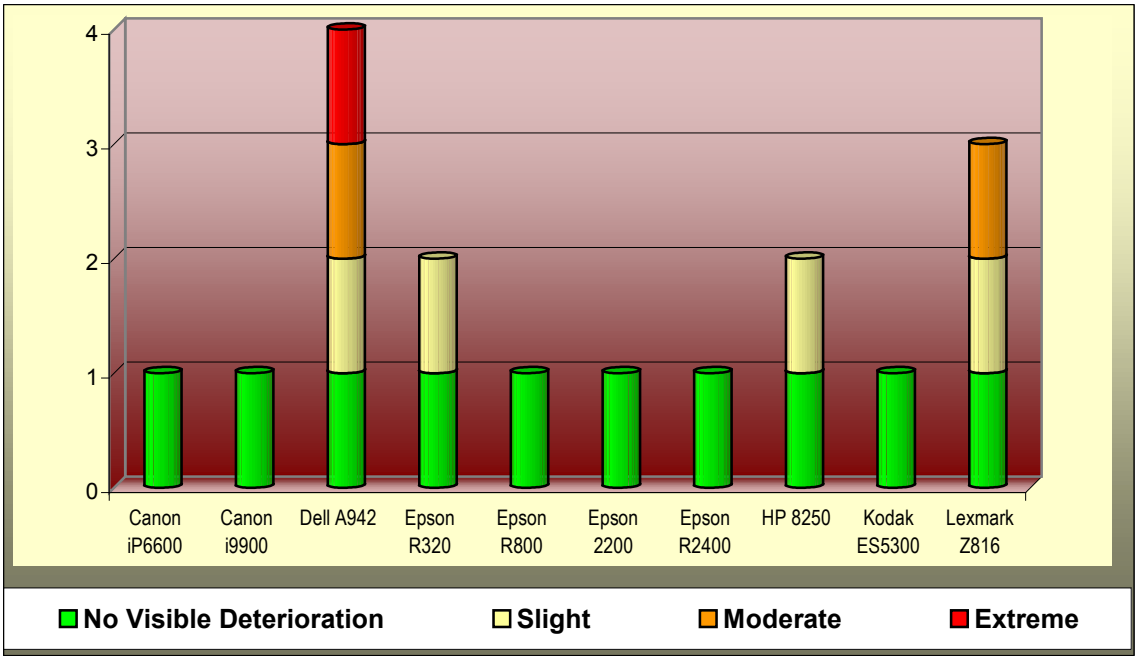


**Figure 2 - Summary of Visual Assessment of High Humidity Keeping Test - Lower is Better**

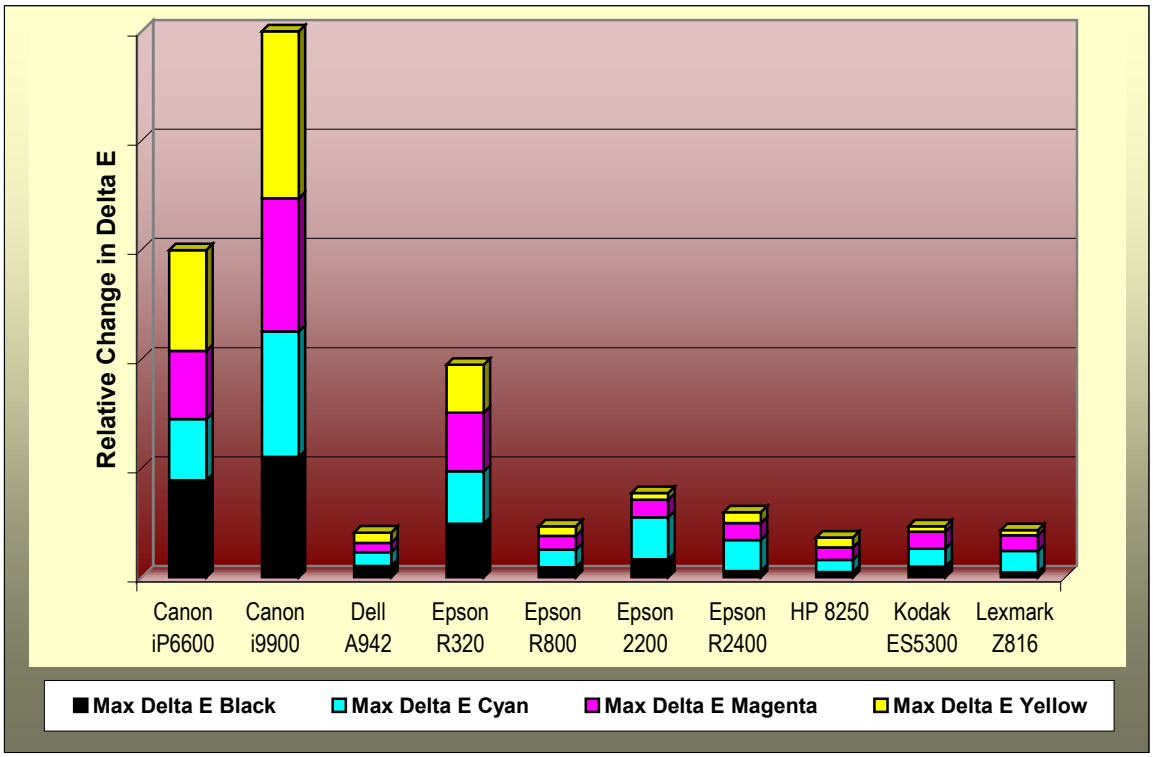


**Figure 3 - Summary of All 1ppm Ozone Exposure Performance - Lower is Better**

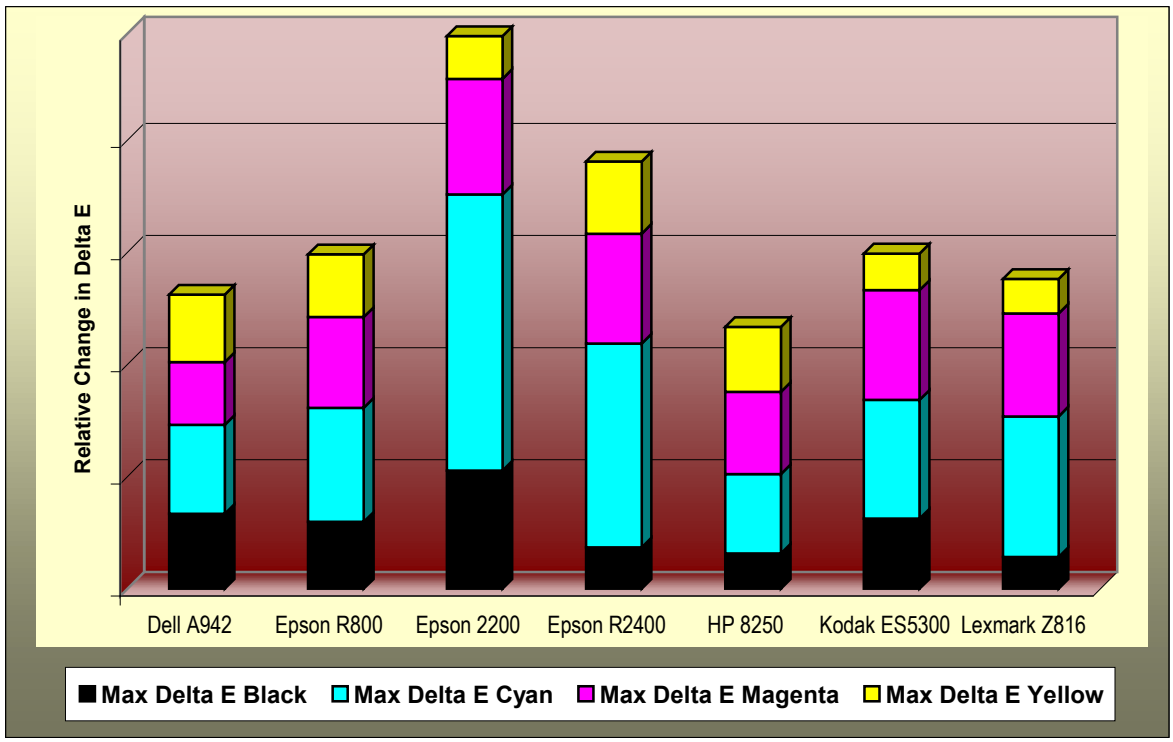


**Figure 4 - Summary of Selected 1ppm Ozone Exposure Performance - Lower is Better (Early Failures Removed)**

The results of these three tests have been summarized in a single graph inserted below as Figure 5.

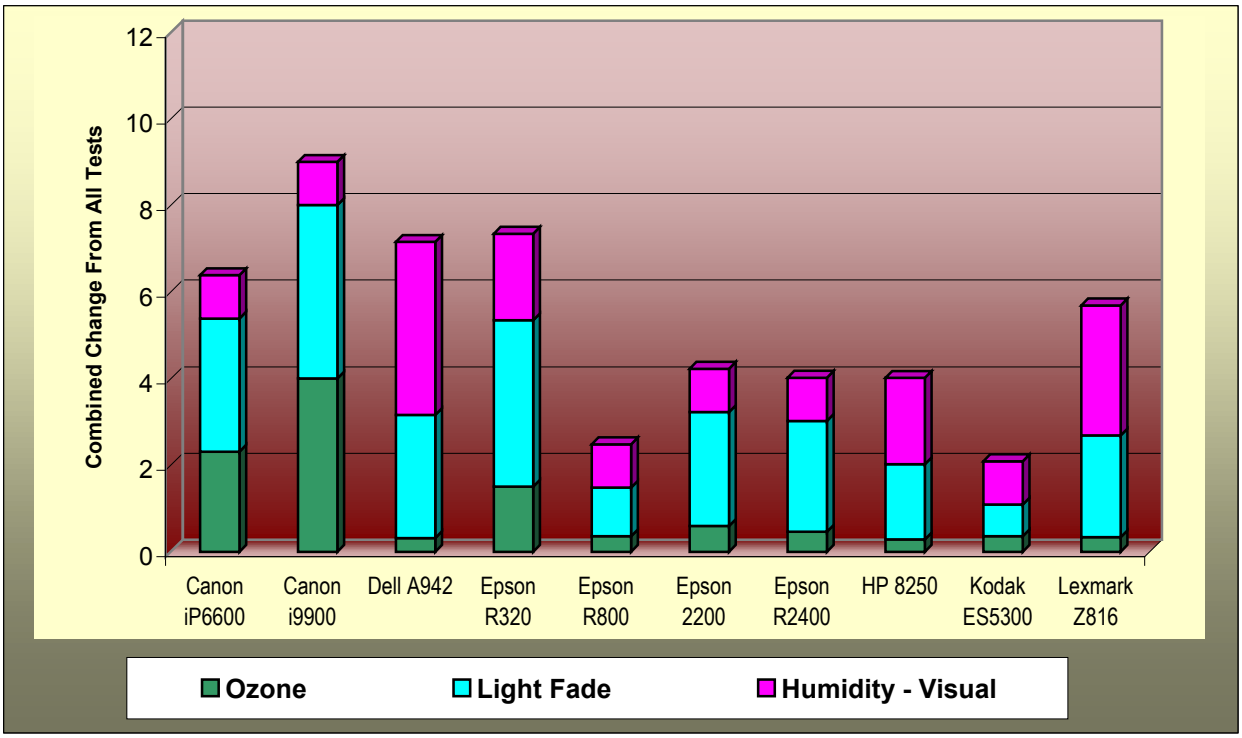


**Figure 5 - Summary of Relative Results of all Three Tests**

When interpreting these charts it should be remembered that the vertical bars all represent relative not absolute values. The numbers on the vertical axis have no absolute significance.

## Overall Summary and Conclusions

Consumers want to know that their images will last without worry or having to provide any kind of special protection. As can be seen from these results, there is a significant variation in performance of the tested inkjet printing systems under the three test conditions that were used. Two of the printing systems tested, the Kodak Easy Share 5300 and the Epson R800 printer provide excellent stability performance in all of the tested conditions. Three more, the HP8250, Epson 2200 and R2400 performed very well under these test conditions. Other systems performed very well in one or more of the tests and were average in the other test or tests.

## 2.0 Torrey Pines Research

Torrey Pines Research is a leading independent product development, product testing, and technology consulting Company since 1986. Headquartered in Carlsbad, CA the company provides advanced technical services to companies in printing technology, materials technology, medical device and diagnostics development, and industrial / consumer product design. The Company also has turnkey manufacturing capabilities both domestically and offshore. TPR provides testing and strategy advisory consulting, often leading to advanced competitive developments, leveraging IP and industry know-how between TPR and its clients. It is common to develop significant new IP with and on behalf of the clients, and to pave new roads into revenue opportunities and untapped or under-served markets.

The Company has been testing print media, toners and inks for more than ten years for a variety of clients. TPR maintains an image stability test laboratory and has internal capabilities to perform accelerated light fade tests using xenon or fluorescent exposure, as well as gas fastness and humidity testing. Client relationships are always confidential, but in some instances our findings are permitted to be published. TPR personnel have presented papers at IS&T and IMI conferences in these areas. In 2007 TPR will complete new testing of prints and media and will begin publishing the findings.

TPR Fellows are a unique group within the company, scientists and engineers with extensive and deep subject matter knowledge, available to consult, research, and/or develop products and services on behalf of clients. They have been responsible for over 1000 patents, demonstrating a tremendous source of experience and scientific knowledge.

TPR was founded in 1986 and continues to operate independently without external investment or long-term debt. TPR has demonstrated expertise in all digital printing technologies, especially electrophotography, inkjet and thermal. To support and augment its product development capabilities, TPR has developed extensive testing capabilities for printer sub-systems and complete systems, starting with early technology feasibility verification to full scale EVT, DVT, PVT, and competitive assessment testing. The company produces scanners, printers, imaging processes (onto media, foods, pharmaceuticals, unique substrates, and more), or devices to coat, deposit or jet all kinds of fluids and materials (wet, dry, or solid).

A heritage of differentiating IP, innovation, technology, and cost-effectiveness comes from years of experience working closely on significant programs with the world's leaders such as J&J, Eastman Kodak, H-P, IBM, Symbol, and many, many more. TPR people (www.tpr.com/tprfellows.htm) have deep experience in materials, process, and product development to the extent that TPR shares hundreds of patents among them with their assignees.

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# 3.0 Background and Description of Test

## 3.1 Image Permanence

Image permanence or image stability has become an important consideration for all involved in the development, purchase and use of photographs.

In general, image permanence is the quality of a print or photo to remain unchanged for many years after its initial production irrespective of any 'normal' environmental conditions.

'Unchanged' means that the original colors, color densities, line definition and other image quality measurements do not change perceptibly to the eye of the observer.

'Normal environments' includes exposure to light from various sources including direct and indirect sunlight and artificial lights, varying temperatures and humidities, and in some cases exposure to low levels of atmospheric pollutants. All of these conditions have been shown to have a harmful affect upon the permanence of photographs made by various imaging processes.

End users would like their photographs to be unchanged in any way when exposed to these environments for long periods of time.

Suppliers of printing materials and equipment would like to assure end users that their photos will last for very long times when exposed to these environments. Unfortunately to prove this capability by exposing them to the typical environments would lead to unacceptably long test times. Therefore the industry has been developing accelerated tests that simulate the extended lifetime by exposing sample prints to higher levels of the 'normal environmental' element for short periods of time.

There are still much discussion about the specifics of these accelerated tests and the exact ratio between the accelerated test time and the expected real lifetime of the prints. However, the relative performance of prints exposed to the same accelerated tests is likely to be correct. The arguments are likely to be about the absolute extrapolated lifetimes, not the relative lifetimes.

The series of tests reported here are intended to show relative permanence performance of some of the various technologies used to make photographs.

## 3.2 Purpose of the Test

The purpose of this test series was to evaluate the image permanence performance of a variety of media and ink combinations. Prints were exposed to a number of tests, which were designed to demonstrate or measure the relative permanence of the image:

- Accelerated fluorescent light exposure at 50 Klux, polycarbonate filtered
- High humidity dark keeping at 24°C / 80% RH
- Ozone exposure at 1 part per million (ppm) concentration

Specific details of the test conditions and duration can be found under the relevant sections of this report. These conditions are similar to those described in a number of independent reports.

## 3.3 Images Used to Make Prints

Kodak provided the digital image forms used to generate prints as well as the prints themselves. The image used for most of the tests is illustrated in Appendix A and consists of several color blocks (57

patches total) including various densities of cyan, magenta, yellow, black, red, green, blue and neutral plus 3 $D_{min}$ patches (unprinted media). The densities were printed as percentage of the color, 10%, 25%, 50%, 75% and 100% patches were printed for each color. Each of these color blocks was measured as part of the measurement cycle in the tests.

In addition, the high humidity dark keeping test used a second image illustrated in Appendix B. This image included bleed patterns, a photo and other sections designed to provide easier visual assessment of changes. The color densities of this image were not measured, it was used for purely visual assessment.

## 3.4 Initial Blind Test

Test prints made using various inkjet printing systems were submitted to TPR for testing. Each print sample was provided with an ID number and no further identification of the sample was made until the test was completed.

TPR completed the test, compiled the data and compared each of the ink/media combinations for their relative performance in each of the subject exposures. TPR then summarized the relative performance of each of the ink/media combinations based on the data. These results were reported as Part A of this document.

## 3.5 Final Print Identification

When this report was completed and provided to Kodak, Kodak then provided TPR with the identification of each of the samples including its ink and media. These results are reported in this document.

A total of ten inkjet printers were identified, including two from Canon, one from Dell, four from Epson, one each from HP, Lexmark and Kodak.

For each of the printers, the manufacturer's recommended ink set was used.

Each printer was used to print samples on the manufacturer's recommended media for photo printing.

The following table shows the sample ID and identifies the printer, inks and media used to make each sample for the light fade and high humidity tests.

| ID | Printer | Ink | Media |
|---|---|---|---|
| 1 | Canon iP6600 | ChromaLife CLI-8 Dye | Kodak Ultra Prem Photo Paper |
| 2 | Canon iP6600 | ChromaLife CLI-8 Dye | Kodak Ultra Prem Photo Paper |
| 3 | Canon iP6600 | ChromaLife CLI-8 Dye | Canon Photo Pro |
| 4 | Canon iP6600 | ChromaLife CLI-8 Dye | Canon Photo Pro |
| 5 | Canon i9900 | Canon i9900 Dyes 8C | Kodak Ultra Prem Photo Paper |
| 6 | Canon i9900 | Canon i9900 Dyes 8C | Kodak Ultra Prem Photo Paper |
| 7 | Canon i9900 | Canon i9900 Dyes 8C | Canon Photo Pro |
| 8 | Canon i9900 | Canon i9900 Dyes 8C | Canon Photo Pro |
| 9 | Dell A942 | Dell A942 | Kodak Ultra Prem Photo Paper |
| 10 | Dell A942 | Dell A942 | Kodak Ultra Prem Photo Paper |
| 11 | Dell A942 | Dell A942 | Dell Prem Photo Paper |
| 12 | Dell A942 | Dell A942 | Dell Prem Photo Paper |
| 13 | Epson R320 | Epson Photo Dyes 6C | Kodak Ultra Prem Photo Paper |
| 14 | Epson R320 | Epson Photo Dyes 6C | Kodak Ultra Prem Photo Paper |
| 15 | Epson R320 | Epson Photo Dyes 6C | Epson Prem Glossy Photo |
| 16 | Epson R320 | Epson Photo Dyes 6C | Epson Prem Glossy Photo |
| 17 | Epson R800 | Epson UltraChrome Hi Gloss 8C | Kodak Ultra Prem Photo Paper |
| 18 | Epson R800 | Epson UltraChrome Hi Gloss 8C | Kodak Ultra Prem Photo Paper |
| 19 | Epson R800 | Epson UltraChrome Hi Gloss 8C | Epson Prem Glossy Photo |
| 20 | Epson R800 | Epson UltraChrome Hi Gloss 8C | Epson Prem Glossy Photo |
| 21 | Epson 2200 | Epson UltraChrome 7C | Kodak Ultra Prem Photo Paper |
| 22 | Epson 2200 | Epson UltraChrome 7C | Kodak Ultra Prem Photo Paper |
| 23 | Epson 2200 | Epson UltraChrome 7C | Epson Prem Glossy Photo |
| 24 | Epson 2200 | Epson UltraChrome 7C | Epson Prem Glossy Photo |
| 25 | Epson R2400 | Epson UltraChrome K3 8C | Kodak Ultra Prem Photo Paper |
| 26 | Epson R2400 | Epson UltraChrome K3 8C | Kodak Ultra Prem Photo Paper |
| 27 | Epson R2400 | Epson UltraChrome K3 8C | Epson Prem Glossy Photo |
| 28 | Epson R2400 | Epson UltraChrome K3 8C | Epson Prem Glossy Photo |
| 29 | HP 8250 | HP Vivera 02 Tanks | Kodak Ultra Prem Photo Paper |
| 30 | HP 8250 | HP Vivera 02 Tanks | Kodak Ultra Prem Photo Paper |
| 31 | HP 8250 | HP Vivera 02 Tanks | HP Prem Plus |
| 32 | HP 8250 | HP Vivera 02 Tanks | HP Prem Plus |
| 33 | Lexmark Z816 | #31 Photo, #33/#35 Color 6C | Kodak Ultra Prem Photo Paper |
| 34 | Lexmark Z816 | #31 Photo, #33/#35 Color 6C | Kodak Ultra Prem Photo Paper |
| 35 | Lexmark Z816 | #31 Photo, #33/#35 Color 6C | Lexmark Prem Glossy Photo |
| 36 | Lexmark Z816 | #31 Photo, #33/#35 Color 6C | Lexmark Prem Glossy Photo |
| 37 | Kodak ES5300 | Kodak ink cartridges | Kodak Ultra Prem Photo Paper |
| 38 | Kodak ES5300 | Kodak ink cartridges | Kodak Ultra Prem Photo Paper |
| 39 | Kodak ES5300 | Kodak ink cartridges | Kodak Ultra Prem Photo Paper |
| 40 | Kodak ES5300 | Kodak ink cartridges | Kodak Ultra Prem Photo Paper |

**Table 1 - Print Sample Identification - Printer, Ink, Media**

## 3.6 Basis for Comparing Print Performance

Although many and various measurements were made on the prints subjected to this test, the results that are reported are based on color changes defined by a value known as ΔE.

The measurement of user perception of color change is a very difficult task. It is safe to say that there is no agreement on what absolute values of various methodologies really mean to the user. Having said that, the most commonly accepted measurement system in use in color science today is the CIE L*a*b* system. This system defines a three dimensional color space in terms of luminance (L*), redness-greenness (a*) and yellowness-blueness (b*). It has been illustrated by the image shown in Figure 5, below.

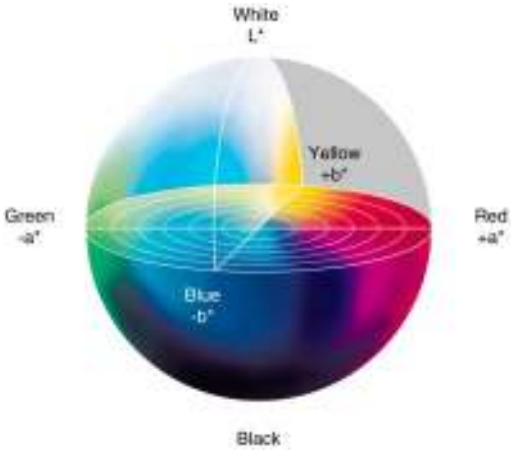


**Figure 4 - L*a*b* Color Space Illustration**

Within this color space, imagine a point in the upper left rear quadrant and another point in the lower left front quadrant. The straight line that would join these points would be called the ΔE or color difference between colors at the two points.

The formula for calculating the distance between two points in a sphere is based on the square root of the sum of the differences of the distances from the origin. In this case, that is:

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

This L*a*b* standard for colorimetric was defined by the International Commission on Illumination (CIE). In the initial definition, a ΔE of 1 was intended to define the smallest perceptible change in a color that could be detected by a human observer. In practice, and especially for untrained observers, it is more likely that the observer would not detect any differences less than a ΔE value of 5. Finally, the casual observer would need a basis for comparison to see even this difference. That is, unless an 'original' was compared with a test print, the casual observer viewing the test print might find nothing wrong with a print that had even greater variance from an 'original'.

The other criterion that has been used in evaluating the data from this test is what is commonly referred to as an 'endpoint'. An endpoint is generally understood to mean a point where the print has changed an unacceptable amount. In this study we have used ΔE of 15 as the endpoint. This endpoint was based on guidance from endpoint illustrations in the recently issued ISO standard 18909-2006. These two criteria, the detectable change threshold and the endpoint, were also selected based upon a

paper presented at NIP17[1]. We have used these criteria because they are easily understood, based upon study, and relate to probable consumer perceptions of change.

Companies also use densitometric change to measure image permanence and this has been most commonly used by those wishing to analyze the changes in inks. Currently densitometric analysis provides more technical information that can be used by scientists in comparing detail and in differentiating between color channels. Densitometric analysis has also been used more widely to predict actual print life from accelerated exposure data such as developed for this report. Since we are not attempting to predict actual print life, we have used the somewhat simpler ΔE criterion as a comparative measure.

Finally, psychophysical analysis of prints is a tool that may be used to assess image quality, and by extension, the effects of image permanence. Psychophysical analysis is currently less advanced that the direct analytical methodologies, but TPR expects to make increasing use of this tool in future analysis[2].

## 3.7 Print Life Based on Test Results

There are a number of methods in use for projecting real print life in years using accelerated exposure life in days. These methods vary in their assumptions for the average exposure in a display environment, the number of hours per day the print is exposed, the type of light, whether the print is covered by a UV filter, density levels to be measured on the print, issues of reciprocity and so on. Although the industry is converging upon a consensus methodology, none has yet been finalized.

The test plan did not require TPR to make a life projection, and TPR was not responsible for making the prints used in the test. For these reasons, and due to the uncertainty of the current extrapolation methods, we will present a relative performance projection based upon the ΔE criteria described above rather than an absolute life in years.

[1] Densitometry versus Colorimetry for Permanence Investigations. *Hoffmann, Bauman and Hagen*. Ilford
[2] Psychophysics and Image Quality, *Plaisted*, TPR

# 4.0 General Procedures

## 4.1 Record Keeping

TPR used a standard PC running Windows 2000 operating system. The provided software read the data from the measurements directly in an extended text format into an Excel spreadsheet. These data were then compiled and analyzed for this report.

The data were saved during each reading session and transmitted to the customer after each group of samples was read.

Each test sample had a unique serial number marked indelibly on the sheet.

The following data were taken using the Gretag Spectrolino – L*, a*, b* and the 4-channel V, R, G, B densities – Status A, D50, 2 deg, Reflection, White base = Abs, Filter = None, Black platform on the Spectrolino

## 4.2 Material Handling During Test

All possible efforts were made to prevent contaminating the samples. All media was handled with lint free, cotton gloves before, during and after testing. Surfaces coming in contact with either surface of the print (work surfaces, instrument faces, etc.) were cleaned prior to each test with pH neutral cotton wipes. Work surfaces were covered with acid free paper during the handling of prints.

Prior to testing prints were stored in acid free storage media of the appropriate type. Each container was marked with the date printed and the job number. Each container contained only one paper/ink type. Each container was kept at 20-25$^0$C and 45-55% RH prior to testing.

After test completion prints were stored in acid free storage media of the appropriate type. Each container was marked with the date printed, the date tested, and the job number. Each container contained only one paper/ink type. Each container contained the results of one test. Prints exposed to different tests were not mixed. Each container was kept at 20-25$^0$C and 45-55% RH.

## 4.3 Laboratory Facilities and Environment

All of the tests were performed at the TPR facility in Rochester, NY. This is an approximately 10,000 sq.ft facility made up of offices and custom laboratories and staffed by scientists, engineers and technicians.

The laboratory environment was maintained at the temperature and humidity levels required to achieve 23$^0$C +/- 2$^0$C, and 50% +/-5% relative humidity at the print sample plane for the duration of the testing activity. Monitoring of these conditions was performed three times daily (morning, noon, evening) to ensure conditions were acceptable.

Ambient ozone levels in the laboratory facilities were monitored twice per day for the duration of the test and verified to be at or below 2 ppb.

## 4.4 General Test Equipment

### 4.4.1 Viewing Booth

A Gretag-Macbeth model Judge II-S controlled lighting booth was used to observe the test prints. This piece of equipment can provide four different types of light for viewing prints:

- Artificial Daylight (fluorescent daylight – 6500K)
- Store Lighting (cool white fluorescent – 4150K)
- Home Lighting (illuminant "A" – 2856K)
- Ultraviolet

The sample viewing area is about 2.5 $ft^2$. For the purposes of this test Home Lighting was used and sample exposure was limited to no more than 5 minutes.

#### 4.4.2 Spectrophotometer

A Gretag-Macbeth Spectrolino spectrophotometer was used to measure the different color patches on each sample before and after each exposure increment or each test. The spectrophotometer was connected through its I/O port and serial interface to the lab PC for data collection.

The Spectrolino was calibrated prior to the test and each day that test measurements were to be taken. The instrument was powered on for at least 30 minutes prior to calibration. Calibration was performed using the manufacturer supplied Calibration Standard.

# 5.0 Accelerated Fluorescent Light Exposure Test

There are no industry standards yet available for accelerated light fade ageing. Standards are expected to be issued in the next several years, and TPR will use those standards as soon as they become available.

Accelerated ageing is done using high output daylight fluorescent lamps to provide a high intensity exposure at the print surface. The tests may be conducted with the prints behind a UV absorbing filter, such as glass or polycarbonate, with airspace, and at controlled temperature and humidity conditions.

The light fade test was roughly as described in the paper *High-Intensity Fluorescent Light-Fading Tests for Digital Output Materials*, by Zinn, Nishimura and Reilly of the RIT Image Permanence Institute at the IS&T 1999 International Conference on Digital Imaging Technologies.

## 5.1 Fluorescent Light Exposure Fixture

A custom light exposure fixture functionally equivalent to the one described in the paper by Zinn and Nishimura was used and is able to provide continuous exposure to as many as (36) 8.5”x11” prints at once.

In practice, TPR limits the exposure area to the central 50% or so of the exposure plane. The reason for this constriction is to insure that the samples are exposed to a uniform intensity throughout the test. In addition, the samples were relocated daily to maintain uniformity.

The sample frames each are capable of holding eighteen 8.5”x11” sheets in landscape format. This frame can be adjusted normal to the lamp array, thus accurately adjusting the intensity of light radiated to the samples. The lamp array oscillates back and forth to eliminate cold spots from the mere spacing of each lamp. The lamps used are GE F72T12CW 1500W cool-white outdoor fluorescent tubes. Each sample plane utilizes twenty-one lamps, which, depending on how distant the sample plane is from the lamp array, will apply 35 or 50 Klux [TBD]. The appropriate distance between the sample plane and the lamp array is determined by the use of an exposure meter. As the lamps age during the test, the sample plane is moved closer to the lamps in order to maintain the exposure level.

In order to maintain the required 23° ± 2° C and 50 ± 5% RH at the sample plane it was necessary to maintain the specific laboratory environment at a lower temperature and higher humidity. In addition, small fans were added to the fixture to cool the lamps and ballasts. The temperature and humidity at the sample plane were measured several times per day.

## 5.2 50 Klux, Polycarbonate Filtered Test

New lamps were set up on the fixture and run for two days without any print samples in place as a burn-in procedure. The sample plane on the subject side of the fixture was covered with a ¼” polycarbonate panel with an air gap of about 19mm between the sample plane and the glass.

Test prints of the image shown in Appendix A were exposed for 24 hours a day, seven days a week, over the course of the testing.

Prints were removed and measured at the following intervals:

0, 7, 28, 56, 64, 112, 224 days

## 5.3 Light Fade Test Measurements

The following data were taken using the Gretag Spectrolino – L*, a*, b* and the 4-channel V, R, G, B densities – Status A, D50, 2 deg, Reflection, White base = Abs, Filter = None, Black platform on Spectrolino

These readings were taken on each of the color patches on the sample noted in Appendices A and B. Samples were removed from their mounting prior to making the measurements.

The values of ΔE for each sample and for most of the color patches are shown in the following tables. Values for the lower density patterns of R, B, G and CMYK are omitted here for the purpose of conciseness.

Within the tables we have chosen to highlight some of the larger changes by using color fill. The values chosen based on the criteria developed above and are as follows:

| | | |
|---|---|---|
| 0 to 5 | Change in ΔE | no fill |
| 5.01 to 15 | Change in ΔE | Yellow Fill |
| 15.01 and higher | Change in ΔE | Orange Fill |

| Color Patch | | Delta E by Sample Number | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Color | % | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | | | | | | | | | | | | | |
| MEDIA | 0 | 1.0 | 1.7 | 4.6 | 4.7 | 1.4 | 1.4 | 4.4 | 4.3 | 1.4 | 1.5 | 0.5 | 0.5 |
| | 0 | 0.7 | 1.6 | 4.5 | 4.6 | 1.3 | 1.3 | 4.3 | 4.2 | 1.5 | 1.6 | 0.5 | 0.5 |
| | 0 | 0.9 | 1.6 | 4.6 | 4.5 | 1.3 | 1.1 | 4.4 | 4.1 | 1.3 | 1.5 | 0.5 | 0.5 |
| | | | | | | | | | | | | | |
| BLACK | 10 | 5.0 | 5.0 | 5.5 | 5.5 | 5.8 | 5.8 | 5.1 | 5.0 | 3.3 | 3.9 | 4.3 | 3.5 |
| | 25 | 11.5 | 11.3 | 8.2 | 8.2 | 11.9 | 11.4 | 7.1 | 7.3 | 12.5 | 13.5 | 6.5 | 6.4 |
| | 40 | 17.5 | 17.6 | 9.6 | 9.6 | 16.8 | 15.5 | 8.2 | 8.6 | 16.6 | 17.0 | 5.2 | 4.8 |
| | 50 | 19.7 | 20.3 | 9.8 | 9.8 | 18.9 | 16.8 | 8.9 | 9.3 | 17.7 | 17.8 | 5.1 | 5.3 |
| | 75 | 23.4 | 23.6 | 9.7 | 9.5 | 22.6 | 20.8 | 16.7 | 16.7 | 17.2 | 17.7 | 7.1 | 7.0 |
| | 100 | 11.0 | 11.6 | 5.5 | 5.6 | 15.4 | 16.1 | 9.1 | 8.8 | 15.0 | 16.0 | 4.5 | 4.6 |
| CYAN | 10 | 2.5 | 2.6 | 4.2 | 4.3 | 3.4 | 3.8 | 4.4 | 4.3 | 2.1 | 2.1 | 0.8 | 0.8 |
| | 25 | 3.3 | 3.4 | 3.9 | 4.1 | 5.7 | 6.0 | 4.6 | 4.5 | 2.7 | 2.8 | 0.8 | 0.8 |
| | 40 | 3.5 | 3.7 | 3.6 | 3.7 | 6.3 | 6.7 | 4.5 | 4.4 | 2.9 | 3.1 | 0.8 | 0.8 |
| | 50 | 2.7 | 3.3 | 3.2 | 3.4 | 5.5 | 5.9 | 4.3 | 4.2 | 4.9 | 5.0 | 1.1 | 1.2 |
| | 75 | 1.6 | 1.9 | 2.6 | 2.8 | 5.2 | 5.3 | 4.4 | 4.3 | 8.1 | 8.3 | 2.5 | 2.7 |
| | 100 | 1.0 | 1.2 | 2.2 | 2.3 | 5.4 | 5.4 | 4.6 | 4.6 | 8.4 | 8.6 | 3.0 | 3.3 |
| MAGENTA | 10 | 11.9 | 12.1 | 12.2 | 12.1 | 13.9 | 13.7 | 11.8 | 11.9 | 3.2 | 3.2 | 4.3 | 3.3 |
| | 25 | 26.9 | 27.3 | 21.6 | 21.7 | 28.9 | 27.9 | 19.9 | 20.1 | 4.4 | 5.5 | 7.7 | 6.0 |
| | 40 | 33.3 | 32.7 | 23.6 | 24.2 | 37.9 | 36.5 | 23.9 | 24.3 | 5.7 | 6.9 | 6.9 | 7.2 |
| | 50 | 30.7 | 30.3 | 22.8 | 23.4 | 42.0 | 41.9 | 28.8 | 29.4 | 8.2 | 9.2 | 7.8 | 8.8 |
| | 75 | 19.4 | 19.7 | 14.1 | 14.6 | 28.4 | 30.0 | 20.1 | 20.2 | 16.7 | 16.9 | 10.6 | 10.2 |
| | 100 | 18.6 | 19.8 | 9.4 | 9.8 | 20.6 | 27.4 | 14.0 | 14.1 | 16.0 | 17.1 | 11.9 | 11.6 |
| YELLOW | 10 | 6.0 | 5.8 | 1.3 | 1.3 | 9.1 | 8.0 | 4.5 | 5.3 | 4.5 | 4.5 | 5.6 | 5.7 |
| | 25 | 18.5 | 18.0 | 8.0 | 8.3 | 21.2 | 18.0 | 12.6 | 14.5 | 17.1 | 17.8 | 15.6 | 15.7 |
| | 40 | 29.4 | 29.2 | 12.5 | 12.6 | 32.7 | 28.8 | 18.2 | 20.3 | 27.7 | 28.0 | 21.6 | 21.0 |
| | 50 | 36.2 | 36.1 | 14.7 | 14.3 | 39.6 | 36.9 | 20.6 | 23.9 | 32.5 | 32.8 | 22.8 | 23.1 |
| | 75 | 45.8 | 45.0 | 15.8 | 15.5 | 42.3 | 40.4 | 20.9 | 24.3 | 37.9 | 38.9 | 20.3 | 20.0 |
| | 100 | 35.9 | 34.7 | 12.9 | 13.3 | 33.4 | 31.1 | 14.9 | 16.3 | 36.5 | 37.6 | 16.0 | 15.2 |
| CMY | 10 | 9.6 | 9.2 | 7.3 | 7.1 | 10.3 | 9.8 | 6.8 | 6.6 | 10.6 | 10.3 | 6.6 | 5.6 |
| | 25 | 20.2 | 20.5 | 9.5 | 9.8 | 19.1 | 17.2 | 8.8 | 9.1 | 17.0 | 17.4 | 4.8 | 4.3 |
| | 40 | 23.1 | 23.4 | 8.9 | 9.0 | 23.2 | 22.4 | 17.8 | 17.6 | 14.7 | 15.6 | 7.3 | 7.1 |
| | 50 | 11.8 | 12.0 | 5.2 | 5.2 | 14.9 | 15.8 | 8.1 | 8.6 | 15.1 | 15.5 | 3.6 | 2.3 |
| | 75 | 11.7 | 11.8 | 5.1 | 5.2 | 15.1 | 16.0 | 8.1 | 8.8 | 14.8 | 15.3 | 3.5 | 2.5 |
| | 100 | 11.1 | 11.6 | 5.1 | 5.3 | 15.0 | 16.2 | 8.0 | 8.8 | 14.5 | 15.1 | 3.0 | 2.5 |
| | | | | | | | | | | | | | |
| RED | 100 | 29.5 | 30.1 | 10.8 | 11.3 | 54.1 | 57.8 | 49.1 | 49.6 | 28.6 | 30.4 | 19.0 | 17.7 |
| GREEN | 100 | 23.2 | 22.5 | 8.0 | 8.1 | 6.3 | 7.8 | 3.7 | 3.8 | 11.4 | 11.9 | 3.8 | 3.7 |
| BLUE | 100 | 10.7 | 10.3 | 7.0 | 7.0 | 14.3 | 13.7 | 11.1 | 11.0 | 17.3 | 17.7 | 9.7 | 9.6 |
| CMYK | 100 | 11.4 | 12.0 | 5.0 | 5.2 | 15.2 | 16.0 | 8.9 | 9.0 | 15.1 | 15.9 | 3.7 | 3.5 |

**Figure 5 - 50 kLux Polycarbonate Summary of ΔE Samples 1 – 12 - 112 days**

| Color Patch | | Delta E by Sample Number | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Color | % | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| | | | | | | | | | | | | | |
| MEDIA | 0 | 1.2 | 1.5 | 0.7 | 0.7 | 1.3 | 1.7 | 0.7 | 0.6 | 1.4 | 1.5 | 0.3 | 0.6 |
| | 0 | 1.2 | 1.4 | 0.7 | 0.7 | 1.2 | 1.6 | 0.7 | 0.5 | 1.3 | 1.5 | 0.5 | 0.5 |
| | 0 | 1.0 | 1.4 | 0.7 | 0.8 | 1.3 | 1.6 | 0.6 | 0.7 | 1.3 | 1.5 | 0.6 | 0.6 |
| | | | | | | | | | | | | | |
| BLACK | 10 | 8.7 | 8.9 | 4.6 | 4.7 | 0.9 | 1.2 | 0.7 | 0.7 | 1.1 | 1.3 | 2.8 | 2.6 |
| | 25 | 12.0 | 12.5 | 9.4 | 9.2 | 1.9 | 1.7 | 2.9 | 3.3 | 4.7 | 4.8 | 7.9 | 8.3 |
| | 40 | 13.5 | 14.4 | 10.9 | 11.2 | 1.5 | 1.5 | 2.4 | 2.4 | 6.5 | 7.1 | 10.1 | 10.9 |
| | 50 | 14.7 | 15.1 | 12.3 | 12.4 | 1.0 | 1.0 | 1.4 | 1.3 | 4.5 | 4.9 | 6.8 | 7.5 |
| | 75 | 15.1 | 15.9 | 3.4 | 3.6 | 1.1 | 1.0 | 0.9 | 0.9 | 0.9 | 1.1 | 1.0 | 0.9 |
| | 100 | 9.5 | 9.8 | 0.8 | 0.8 | 0.6 | 0.9 | 1.3 | 0.5 | 1.0 | 0.9 | 0.6 | 0.7 |
| CYAN | 10 | 4.7 | 4.8 | 1.3 | 1.5 | 1.1 | 1.7 | 0.9 | 1.0 | 1.9 | 2.1 | 1.6 | 1.7 |
| | 25 | 7.0 | 7.3 | 2.1 | 2.2 | 1.4 | 2.0 | 1.4 | 1.4 | 2.3 | 2.5 | 2.2 | 2.3 |
| | 40 | 7.4 | 7.7 | 2.2 | 2.5 | 1.6 | 2.0 | 1.4 | 1.6 | 2.3 | 2.6 | 2.2 | 2.3 |
| | 50 | 6.5 | 6.7 | 2.1 | 2.3 | 1.5 | 2.0 | 1.5 | 1.6 | 2.0 | 2.6 | 1.9 | 2.1 |
| | 75 | 3.2 | 4.1 | 2.5 | 3.1 | 2.1 | 2.8 | 2.1 | 2.1 | 2.3 | 3.5 | 1.8 | 1.8 |
| | 100 | 4.2 | 4.7 | 1.6 | 2.1 | 2.3 | 3.1 | 1.7 | 1.7 | 1.5 | 2.5 | 1.7 | 1.9 |
| MAGENTA | 10 | 13.2 | 13.7 | 8.1 | 8.4 | 2.6 | 2.4 | 2.0 | 2.7 | 3.1 | 3.8 | 1.5 | 2.6 |
| | 25 | 26.2 | 27.9 | 13.7 | 14.3 | 3.6 | 3.6 | 2.7 | 3.1 | 4.3 | 5.4 | 3.4 | 3.9 |
| | 40 | 32.2 | 35.1 | 17.1 | 17.8 | 4.0 | 2.9 | 3.0 | 3.7 | 5.3 | 6.9 | 5.0 | 6.1 |
| | 50 | 31.8 | 33.5 | 17.8 | 19.5 | 3.8 | 3.4 | 3.1 | 3.5 | 5.8 | 6.9 | 3.9 | 6.1 |
| | 75 | 20.6 | 20.6 | 13.0 | 13.8 | 3.7 | 3.4 | 3.0 | 3.0 | 6.7 | 8.0 | 5.4 | 6.7 |
| | 100 | 16.1 | 16.5 | 9.9 | 10.0 | 2.7 | 1.9 | 1.6 | 1.5 | 6.9 | 7.2 | 8.1 | 8.2 |
| YELLOW | 10 | 2.9 | 2.8 | 5.5 | 5.7 | 0.9 | 0.6 | 1.6 | 1.7 | 0.6 | 0.6 | 4.1 | 4.7 |
| | 25 | 9.5 | 9.6 | 14.2 | 14.9 | 2.0 | 1.0 | 3.1 | 3.0 | 2.7 | 3.0 | 9.3 | 11.4 |
| | 40 | 14.4 | 15.3 | 21.6 | 22.7 | 1.9 | 1.3 | 2.2 | 2.4 | 5.2 | 5.2 | 14.6 | 18.1 |
| | 50 | 15.9 | 17.8 | 23.0 | 24.7 | 0.9 | 0.8 | 1.1 | 1.2 | 6.8 | 7.5 | 15.3 | 21.0 |
| | 75 | 18.8 | 21.4 | 19.2 | 20.5 | 1.6 | 1.2 | 1.9 | 1.9 | 6.1 | 6.1 | 10.8 | 13.8 |
| | 100 | 19.5 | 20.5 | 11.2 | 11.2 | 2.0 | 1.9 | 2.3 | 3.1 | 2.4 | 2.8 | 2.4 | 2.9 |
| CMY | 10 | 11.3 | 11.8 | 8.0 | 8.0 | 1.8 | 1.2 | 2.3 | 2.5 | 2.9 | 2.8 | 5.6 | 5.1 |
| | 25 | 14.3 | 15.4 | 12.1 | 12.4 | 1.0 | 1.1 | 1.3 | 1.3 | 4.6 | 4.6 | 7.1 | 6.8 |
| | 40 | 12.1 | 12.8 | 0.7 | 1.5 | 1.1 | 1.2 | 0.9 | 0.9 | 1.4 | 1.1 | 0.7 | 1.1 |
| | 50 | 9.4 | 9.7 | 0.8 | 1.0 | 0.8 | 0.8 | 0.6 | 0.4 | 1.0 | 0.9 | 1.6 | 1.1 |
| | 75 | 9.4 | 9.5 | 0.6 | 0.7 | 0.7 | 0.9 | 0.4 | 0.4 | 1.0 | 1.0 | 1.0 | 0.8 |
| | 100 | 9.0 | 9.4 | 0.3 | 0.9 | 1.1 | 1.0 | 0.5 | 0.4 | 0.9 | 1.1 | 1.2 | 0.9 |
| | | | | | | | | | | | | | |
| RED | 100 | 22.8 | 22.9 | 13.0 | 13.3 | 1.0 | 1.2 | 1.1 | 1.2 | 2.7 | 3.7 | 4.0 | 4.1 |
| GREEN | 100 | 11.6 | 12.1 | 5.3 | 3.4 | 1.2 | 1.0 | 1.7 | 2.0 | 8.0 | 9.5 | 6.2 | 7.1 |
| BLUE | 100 | 17.7 | 18.8 | 11.0 | 10.7 | 1.5 | 0.5 | 0.3 | 0.7 | 7.1 | 5.8 | 7.2 | 7.0 |
| CMYK | 100 | 9.4 | 9.9 | 0.5 | 0.8 | 1.0 | 0.8 | 0.4 | 0.4 | 0.8 | 1.0 | 0.8 | 0.6 |

**Figure 6 - 50 kLux Polycarbonate Summary of ΔE Samples 13-24 –112 days**

| Color Patch | | Delta E by Sample Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Color | % | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| | | | | | | | | | |
| MEDIA | 0 | 1.7 | 1.8 | 0.6 | 0.5 | 1.6 | 1.5 | 0.8 | 0.9 |
| | 0 | 1.7 | 1.8 | 0.4 | 0.5 | 1.5 | 1.5 | 0.8 | 1.0 |
| | 0 | 1.6 | 1.8 | 0.5 | 0.5 | 1.5 | 1.5 | 0.8 | 0.9 |
| | | | | | | | | | |
| BLACK | 10 | 0.9 | 1.2 | 2.5 | 2.3 | 1.6 | 1.5 | 1.3 | 1.4 |
| | 25 | 1.3 | 1.9 | 2.2 | 2.1 | 6.2 | 6.9 | 3.3 | 3.3 |
| | 40 | 1.6 | 2.2 | 2.9 | 3.0 | 12.4 | 12.2 | 4.7 | 4.7 |
| | 50 | 1.5 | 2.2 | 2.9 | 2.9 | 15.5 | 14.8 | 6.7 | 5.6 |
| | 75 | 1.3 | 1.6 | 1.4 | 1.6 | 12.4 | 12.7 | 5.4 | 5.5 |
| | 100 | 0.7 | 1.1 | 0.9 | 0.8 | 19.4 | 18.0 | 3.4 | 4.5 |
| CYAN | 10 | 2.1 | 2.1 | 0.9 | 0.9 | 2.3 | 2.1 | 1.0 | 1.1 |
| | 25 | 2.5 | 2.6 | 1.5 | 1.4 | 3.5 | 3.6 | 1.2 | 1.3 |
| | 40 | 2.2 | 2.6 | 1.5 | 1.5 | 4.4 | 4.5 | 1.3 | 1.4 |
| | 50 | 2.6 | 3.4 | 1.2 | 1.1 | 4.9 | 4.5 | 1.4 | 1.5 |
| | 75 | 2.5 | 3.8 | 1.2 | 1.3 | 5.3 | 5.4 | 1.5 | 1.6 |
| | 100 | 1.8 | 2.6 | 1.3 | 1.3 | 4.8 | 4.7 | 1.7 | 1.7 |
| MAGENTA | 10 | 3.2 | 4.5 | 5.1 | 3.2 | 2.3 | 2.4 | 1.4 | 1.2 |
| | 25 | 5.9 | 5.4 | 5.1 | 3.6 | 4.5 | 4.7 | 2.2 | 1.5 |
| | 40 | 4.4 | 5.3 | 4.3 | 4.0 | 7.0 | 7.4 | 1.9 | 1.8 |
| | 50 | 4.5 | 4.9 | 4.1 | 4.1 | 8.2 | 9.7 | 2.1 | 1.8 |
| | 75 | 3.1 | 2.0 | 1.4 | 1.4 | 10.2 | 10.0 | 8.6 | 5.6 |
| | 100 | 3.0 | 2.7 | 2.4 | 2.0 | 10.3 | 9.9 | 5.8 | 6.4 |
| YELLOW | 10 | 2.0 | 1.9 | 8.9 | 9.2 | 1.4 | 1.6 | 2.0 | 1.5 |
| | 25 | 6.5 | 6.4 | 20.1 | 21.2 | 8.8 | 9.7 | 7.0 | 5.7 |
| | 40 | 7.4 | 7.4 | 22.8 | 26.5 | 17.5 | 18.7 | 9.5 | 9.7 |
| | 50 | 7.5 | 7.1 | 21.9 | 24.6 | 23.5 | 24.5 | 11.2 | 11.7 |
| | 75 | 4.3 | 3.7 | 10.1 | 11.9 | 19.9 | 19.0 | 10.0 | 10.3 |
| | 100 | 2.9 | 3.7 | 3.6 | 3.3 | 18.1 | 17.2 | 8.4 | 9.0 |
| CMY | 10 | 1.6 | 2.1 | 2.1 | 2.0 | 4.6 | 5.1 | 2.7 | 2.7 |
| | 25 | 1.7 | 2.2 | 2.8 | 2.8 | 15.1 | 14.9 | 5.8 | 5.5 |
| | 40 | 1.3 | 1.3 | 1.1 | 1.2 | 11.6 | 11.4 | 4.7 | 4.8 |
| | 50 | 0.9 | 0.8 | 0.7 | 0.7 | 19.4 | 16.9 | 3.8 | 4.5 |
| | 75 | 1.0 | 0.9 | 0.8 | 0.8 | 19.1 | 17.5 | 3.7 | 4.5 |
| | 100 | 0.9 | 0.8 | 1.0 | 0.7 | 18.9 | 18.2 | 3.8 | 4.9 |
| | | | | | | | | | |
| RED | 100 | 2.3 | 4.3 | 5.2 | 3.3 | 16.6 | 15.0 | 4.1 | 4.5 |
| GREEN | 100 | 7.0 | 6.9 | 9.3 | 8.0 | 16.7 | 16.1 | 7.9 | 8.6 |
| BLUE | 100 | 3.1 | 2.6 | 1.7 | 1.7 | 12.7 | 12.3 | 4.6 | 4.3 |
| CMYK | 100 | 0.9 | 1.0 | 0.7 | 0.6 | 17.5 | 17.6 | 3.5 | 4.4 |

**Figure 7 - 50 kLux Polycarbonate Summary of ΔE Samples 25-32 -112 days**

| Color Patch | | Delta E by Sample Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Color | % | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
| | | | | | | | | | |
| MEDIA | 0 | 1.4 | 1.2 | 1.2 | 1.2 | 2.4 | 2.1 | 2.6 | 2.6 |
| | 0 | 1.5 | 1.3 | 1.3 | 1.1 | 2.2 | 2.0 | 2.6 | 2.8 |
| | 0 | 1.4 | 1.8 | 1.3 | 1.2 | 2.2 | 2.4 | 2.6 | 2.6 |
| | | | | | | | | | |
| BLACK | 10 | 1.4 | 1.8 | 2.0 | 2.0 | 1.8 | 1.9 | 2.2 | 2.3 |
| | 25 | 9.2 | 10.1 | 3.7 | 5.9 | 1.6 | 1.7 | 1.9 | 2.0 |
| | 40 | 15.3 | 16.2 | 4.2 | 6.9 | 1.6 | 1.7 | 1.8 | 1.8 |
| | 50 | 16.1 | 17.0 | 5.7 | 6.9 | 1.6 | 1.7 | 1.7 | 1.7 |
| | 75 | 16.5 | 17.2 | 7.1 | 7.2 | 1.5 | 1.6 | 1.3 | 1.4 |
| | 100 | 12.9 | 17.3 | 3.1 | 3.4 | 0.5 | 0.5 | 0.7 | 0.6 |
| CYAN | 10 | 1.8 | 1.9 | 1.5 | 1.1 | 2.0 | 2.1 | 2.7 | 2.5 |
| | 25 | 2.8 | 3.1 | 1.5 | 1.3 | 1.8 | 2.0 | 2.8 | 2.6 |
| | 40 | 3.0 | 3.3 | 1.6 | 1.2 | 1.8 | 2.0 | 2.8 | 2.5 |
| | 50 | 4.0 | 4.3 | 2.1 | 1.8 | 1.8 | 2.1 | 2.6 | 2.5 |
| | 75 | 7.9 | 8.3 | 3.7 | 3.3 | 1.7 | 2.1 | 2.3 | 2.3 |
| | 100 | 8.6 | 8.9 | 4.6 | 3.9 | 1.8 | 1.9 | 2.1 | 1.9 |
| MAGENTA | 10 | 2.9 | 3.4 | 6.4 | 4.6 | 3.8 | 3.8 | 4.4 | 4.2 |
| | 25 | 5.9 | 5.7 | 10.7 | 6.8 | 5.8 | 6.1 | 6.2 | 6.3 |
| | 40 | 6.9 | 7.1 | 14.3 | 15.9 | 7.4 | 7.7 | 7.5 | 7.4 |
| | 50 | 10.1 | 10.0 | 11.3 | 8.3 | 8.3 | 8.1 | 8.0 | 7.8 |
| | 75 | 18.9 | 19.6 | 11.2 | 8.3 | 7.9 | 7.9 | 7.6 | 7.6 |
| | 100 | 18.4 | 19.3 | 7.1 | 7.0 | 6.5 | 6.2 | 6.5 | 6.4 |
| YELLOW | 10 | 4.8 | 4.8 | 6.3 | 6.2 | 1.2 | 1.5 | 2.2 | 2.2 |
| | 25 | 15.2 | 15.9 | 14.9 | 13.7 | 0.5 | 0.4 | 0.9 | 1.0 |
| | 40 | 22.9 | 24.1 | 17.6 | 16.2 | 0.9 | 1.0 | 0.5 | 0.5 |
| | 50 | 26.9 | 28.7 | 17.4 | 16.5 | 1.1 | 1.0 | 0.7 | 0.7 |
| | 75 | 36.6 | 38.4 | 15.2 | 16.1 | 1.4 | 1.3 | 1.2 | 1.1 |
| | 100 | 35.6 | 36.8 | 12.2 | 13.4 | 0.8 | 1.0 | 0.8 | 0.9 |
| CMY | 10 | 6.5 | 7.5 | 3.6 | 4.3 | 2.2 | 2.5 | 3.1 | 3.1 |
| | 25 | 15.8 | 16.5 | 5.3 | 6.0 | 2.5 | 2.6 | 3.0 | 3.1 |
| | 40 | 14.2 | 15.5 | 5.8 | 6.2 | 2.8 | 2.7 | 2.6 | 2.7 |
| | 50 | 16.4 | 17.3 | 2.8 | 3.4 | 2.8 | 2.7 | 2.2 | 2.4 |
| | 75 | 16.4 | 17.0 | 2.8 | 3.3 | 1.7 | 1.6 | 0.8 | 0.9 |
| | 100 | 16.0 | 17.0 | 2.8 | 3.6 | 1.2 | 1.5 | 1.2 | 0.8 |
| | | | | | | | | | |
| RED | 100 | 28.0 | 27.9 | 15.8 | 16.5 | 2.4 | 2.7 | 2.1 | 2.2 |
| GREEN | 100 | 10.9 | 11.6 | 4.7 | 4.4 | 0.8 | 1.3 | 1.2 | 1.6 |
| BLUE | 100 | 22.6 | 21.0 | 10.9 | 10.6 | 10.6 | 10.7 | 9.1 | 9.3 |
| CMYK | 100 | 16.2 | 17.5 | 3.0 | 3.2 | 2.3 | 2.3 | 1.8 | 1.9 |

**Figure 8 - 50 kLux Polycarbonate Summary of ΔE Samples 33-40 - 112 days**

| Color Patch | | 50 kLux Delta E by Sample Number - 224 days | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Color | % | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | | | | | | | | | | | | | |
| MEDIA | 0 | 1.3 | 2.0 | 4.2 | 4.2 | 1.7 | 1.7 | 4.0 | 4.1 | 1.7 | 1.9 | 0.6 | 0.6 |
| | 0 | 0.9 | 1.9 | 4.1 | 4.2 | 1.7 | 1.7 | 4.0 | 4.1 | 1.8 | 2.0 | 0.7 | 0.6 |
| | 0 | 1.2 | 2.0 | 4.3 | 4.2 | 1.6 | 1.4 | 4.1 | 4.0 | 1.6 | 1.8 | 0.7 | 0.6 |
| | | | | | | | | | | | | | |
| BLACK | 10 | 6.0 | 6.0 | 6.1 | 6.0 | 7.1 | 7.3 | 6.2 | 6.1 | 4.3 | 4.7 | 5.2 | 4.6 |
| | 25 | 13.6 | 13.5 | 11.4 | 11.3 | 15.1 | 15.1 | 10.2 | 10.4 | 15.6 | 16.4 | 12.0 | 11.9 |
| | 40 | 20.4 | 20.4 | 15.0 | 14.8 | 21.9 | 21.8 | 12.6 | 12.8 | 23.8 | 24.3 | 8.7 | 8.8 |
| | 50 | 22.8 | 23.3 | 16.2 | 16.0 | 25.6 | 25.5 | 13.8 | 14.1 | 26.1 | 26.0 | 8.1 | 7.9 |
| | 75 | 28.7 | 29.1 | 16.9 | 16.6 | 31.3 | 31.0 | 22.4 | 22.5 | 25.0 | 25.3 | 11.2 | 10.8 |
| | 100 | 18.7 | 18.6 | 12.0 | 12.6 | 24.9 | 25.6 | 22.6 | 21.8 | 21.9 | 22.8 | 7.2 | 7.0 |
| CYAN | 10 | 4.1 | 4.2 | 4.3 | 4.3 | 5.6 | 6.1 | 5.0 | 5.0 | 4.1 | 4.2 | 1.7 | 1.8 |
| | 25 | 6.3 | 6.3 | 4.6 | 4.6 | 9.7 | 10.0 | 6.8 | 6.8 | 7.0 | 7.2 | 1.8 | 1.8 |
| | 40 | 7.1 | 7.3 | 4.6 | 4.6 | 10.8 | 11.3 | 7.4 | 7.3 | 7.2 | 7.5 | 1.9 | 1.7 |
| | 50 | 5.4 | 6.6 | 4.1 | 4.2 | 9.6 | 10.1 | 7.1 | 6.9 | 9.8 | 10.0 | 2.4 | 2.5 |
| | 75 | 3.4 | 3.6 | 3.3 | 3.3 | 9.0 | 9.3 | 7.8 | 7.7 | 14.6 | 15.0 | 4.2 | 4.3 |
| | 100 | 2.3 | 2.4 | 3.4 | 3.3 | 9.4 | 9.6 | 8.3 | 8.3 | 15.2 | 15.5 | 5.0 | 5.1 |
| MAGENTA | 10 | 14.7 | 14.9 | 14.6 | 14.4 | 17.2 | 17.3 | 14.9 | 15.0 | 4.1 | 4.1 | 5.7 | 4.5 |
| | 25 | 34.7 | 35.3 | 28.5 | 28.3 | 38.1 | 37.6 | 27.7 | 27.7 | 6.0 | 7.1 | 9.1 | 7.4 |
| | 40 | 45.0 | 44.5 | 33.6 | 34.1 | 52.5 | 51.5 | 35.0 | 35.3 | 7.8 | 8.8 | 8.9 | 8.8 |
| | 50 | 43.2 | 42.7 | 33.5 | 34.1 | 58.8 | 58.8 | 41.7 | 42.1 | 11.3 | 12.0 | 9.9 | 10.8 |
| | 75 | 27.6 | 28.1 | 20.5 | 21.1 | 44.9 | 45.9 | 34.4 | 34.4 | 24.0 | 24.5 | 15.5 | 14.8 |
| | 100 | 25.6 | 27.0 | 12.1 | 12.3 | 33.5 | 39.7 | 25.0 | 24.9 | 23.9 | 25.2 | 17.2 | 16.8 |
| YELLOW | 10 | 7.5 | 7.5 | 4.7 | 4.6 | 11.5 | 11.2 | 8.0 | 8.7 | 5.9 | 5.9 | 7.0 | 7.1 |
| | 25 | 23.0 | 22.9 | 15.5 | 15.6 | 27.5 | 26.3 | 20.2 | 21.8 | 22.8 | 23.4 | 22.2 | 22.4 |
| | 40 | 37.6 | 37.6 | 23.5 | 23.1 | 43.9 | 41.5 | 29.8 | 31.9 | 38.0 | 38.3 | 34.9 | 34.7 |
| | 50 | 46.9 | 47.2 | 27.5 | 26.5 | 55.3 | 54.5 | 34.6 | 38.6 | 45.9 | 46.1 | 40.9 | 40.7 |
| | 75 | 62.8 | 62.6 | 31.3 | 29.6 | 64.6 | 64.9 | 39.9 | 43.7 | 56.6 | 58.2 | 45.9 | 44.6 |
| | 100 | 53.1 | 52.1 | 28.8 | 28.1 | 54.3 | 53.2 | 32.0 | 34.2 | 56.4 | 57.9 | 39.0 | 36.8 |
| CMY | 10 | 11.4 | 11.0 | 9.7 | 9.4 | 13.0 | 13.1 | 9.5 | 9.3 | 12.8 | 12.9 | 11.4 | 10.4 |
| | 25 | 23.3 | 23.4 | 15.8 | 16.0 | 25.3 | 24.7 | 13.9 | 14.0 | 25.5 | 25.8 | 7.5 | 6.7 |
| | 40 | 28.9 | 29.6 | 16.1 | 16.0 | 32.1 | 31.9 | 24.5 | 24.2 | 22.0 | 23.1 | 10.8 | 10.7 |
| | 50 | 19.4 | 19.3 | 12.2 | 12.4 | 24.2 | 25.1 | 20.7 | 20.8 | 21.9 | 22.2 | 6.3 | 4.5 |
| | 75 | 19.1 | 18.9 | 11.7 | 12.1 | 24.3 | 25.3 | 20.8 | 21.0 | 21.5 | 22.0 | 6.1 | 4.9 |
| | 100 | 18.5 | 18.5 | 12.0 | 12.0 | 24.3 | 25.4 | 20.6 | 20.8 | 21.1 | 21.9 | 5.9 | 4.9 |
| | | | | | | | | | | | | | |
| RED | 100 | 38.3 | 38.5 | 20.6 | 21.3 | 63.4 | 66.4 | 57.0 | 57.3 | 37.2 | 38.9 | 33.1 | 31.4 |
| GREEN | 100 | 33.4 | 32.8 | 15.3 | 15.6 | 8.4 | 9.9 | 5.2 | 5.2 | 21.7 | 22.3 | 6.0 | 5.8 |
| BLUE | 100 | 16.0 | 15.6 | 11.5 | 11.5 | 21.6 | 21.4 | 17.9 | 17.8 | 23.0 | 23.5 | 14.2 | 14.2 |
| CMYK | 100 | 19.3 | 19.2 | 11.4 | 12.1 | 24.6 | 25.1 | 22.1 | 21.5 | 21.8 | 22.7 | 6.3 | 6.0 |

**Figure 9 - 50 kLux Polycarbonate Summary of ΔE Samples 1 – 12 - 224 days**

| Color Patch | | 50 kLux Delta E by Sample Number - 224 days | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Color | % | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| | | | | | | | | | | | | | |
| MEDIA | 0 | 1.4 | 1.7 | 1.4 | 1.3 | 1.6 | 2.0 | 1.2 | 1.2 | 1.7 | 1.8 | 0.8 | 1.2 |
| | 0 | 1.4 | 1.7 | 1.3 | 1.3 | 1.5 | 1.9 | 1.2 | 1.2 | 1.6 | 1.8 | 1.1 | 1.2 |
| | 0 | 1.3 | 1.7 | 1.3 | 1.4 | 1.7 | 1.9 | 1.1 | 1.2 | 1.6 | 1.8 | 1.3 | 1.1 |
| | | | | | | | | | | | | | |
| BLACK | 10 | 9.9 | 10.2 | 7.4 | 7.5 | 1.9 | 1.8 | 2.6 | 2.9 | 1.8 | 1.6 | 5.4 | 5.5 |
| | 25 | 16.2 | 16.9 | 16.8 | 17.1 | 7.5 | 6.9 | 10.6 | 11.3 | 11.2 | 11.9 | 16.6 | 17.0 |
| | 40 | 19.3 | 20.3 | 20.7 | 21.4 | 6.3 | 6.1 | 10.1 | 9.9 | 15.9 | 17.3 | 23.0 | 24.1 |
| | 50 | 19.6 | 20.0 | 19.5 | 19.5 | 3.9 | 3.9 | 5.9 | 5.4 | 10.6 | 10.9 | 16.7 | 17.3 |
| | 75 | 19.8 | 20.4 | 7.4 | 7.5 | 1.7 | 1.7 | 1.8 | 1.7 | 1.2 | 1.4 | 1.1 | 1.0 |
| | 100 | 14.2 | 14.7 | 1.5 | 1.5 | 0.8 | 1.0 | 0.8 | 0.8 | 1.0 | 1.3 | 0.8 | 0.8 |
| CYAN | 10 | 7.5 | 7.7 | 3.0 | 3.5 | 2.5 | 3.1 | 2.6 | 2.7 | 3.3 | 3.7 | 4.2 | 4.2 |
| | 25 | 12.1 | 12.5 | 5.9 | 5.9 | 3.6 | 4.2 | 4.0 | 4.0 | 4.3 | 4.5 | 5.6 | 5.8 |
| | 40 | 13.3 | 13.8 | 6.7 | 6.8 | 3.8 | 4.3 | 3.9 | 4.2 | 4.0 | 4.7 | 5.2 | 5.3 |
| | 50 | 11.9 | 12.0 | 5.2 | 6.0 | 3.7 | 4.1 | 3.9 | 3.9 | 3.5 | 4.3 | 3.9 | 4.3 |
| | 75 | 6.1 | 7.0 | 4.8 | 5.5 | 3.3 | 3.9 | 3.6 | 3.6 | 3.3 | 4.4 | 3.0 | 3.0 |
| | 100 | 7.4 | 8.1 | 4.8 | 5.6 | 3.2 | 4.0 | 2.4 | 2.6 | 2.9 | 4.2 | 4.4 | 4.6 |
| MAGENTA | 10 | 15.4 | 16.0 | 12.5 | 12.8 | 3.7 | 3.6 | 3.2 | 3.7 | 4.0 | 4.5 | 2.5 | 3.6 |
| | 25 | 32.1 | 34.0 | 22.4 | 23.3 | 5.3 | 5.5 | 4.9 | 4.8 | 5.8 | 6.4 | 4.7 | 5.1 |
| | 40 | 41.7 | 45.1 | 29.2 | 30.2 | 6.3 | 5.9 | 5.7 | 5.8 | 6.7 | 8.0 | 6.9 | 7.2 |
| | 50 | 42.6 | 45.0 | 30.8 | 32.9 | 6.0 | 6.3 | 5.4 | 5.7 | 7.2 | 8.3 | 5.5 | 7.5 |
| | 75 | 28.1 | 28.4 | 23.6 | 24.4 | 5.5 | 5.3 | 5.2 | 5.1 | 8.7 | 9.7 | 7.6 | 8.6 |
| | 100 | 22.1 | 22.5 | 17.4 | 17.7 | 3.9 | 3.6 | 2.7 | 2.6 | 8.3 | 8.5 | 10.0 | 9.8 |
| YELLOW | 10 | 6.2 | 6.2 | 9.4 | 9.5 | 4.0 | 2.6 | 6.3 | 6.6 | 2.2 | 2.2 | 7.7 | 7.7 |
| | 25 | 19.1 | 19.3 | 25.8 | 26.3 | 6.9 | 5.5 | 11.4 | 11.2 | 7.4 | 8.2 | 19.4 | 20.8 |
| | 40 | 29.7 | 31.0 | 41.1 | 42.1 | 6.3 | 5.5 | 9.8 | 10.1 | 13.3 | 13.3 | 32.2 | 35.3 |
| | 50 | 33.9 | 36.6 | 47.3 | 49.0 | 3.9 | 3.6 | 6.2 | 6.3 | 16.8 | 18.2 | 35.5 | 45.6 |
| | 75 | 39.1 | 42.9 | 49.8 | 51.8 | 2.4 | 1.9 | 2.6 | 2.3 | 16.4 | 16.9 | 33.8 | 40.9 |
| | 100 | 36.0 | 37.2 | 34.7 | 37.2 | 2.9 | 2.9 | 3.1 | 4.2 | 4.1 | 4.2 | 5.0 | 6.1 |
| CMY | 10 | 14.6 | 15.2 | 13.9 | 14.2 | 6.9 | 5.2 | 8.1 | 8.2 | 7.5 | 7.8 | 12.0 | 11.6 |
| | 25 | 19.0 | 20.3 | 19.2 | 19.6 | 3.8 | 3.6 | 5.3 | 5.4 | 10.8 | 11.1 | 16.1 | 16.3 |
| | 40 | 17.4 | 18.0 | 2.7 | 3.4 | 1.4 | 1.5 | 1.3 | 1.2 | 1.7 | 1.3 | 0.9 | 1.2 |
| | 50 | 14.0 | 14.4 | 1.9 | 1.7 | 1.2 | 1.0 | 0.9 | 0.7 | 1.1 | 1.1 | 1.6 | 1.3 |
| | 75 | 13.9 | 14.3 | 1.2 | 1.3 | 1.1 | 1.2 | 0.7 | 0.7 | 1.1 | 1.2 | 1.3 | 1.0 |
| | 100 | 13.6 | 14.1 | 1.2 | 1.5 | 1.2 | 1.1 | 0.9 | 1.0 | 1.2 | 1.3 | 1.5 | 1.3 |
| | | | | | | | | | | | | | |
| RED | 100 | 33.6 | 33.5 | 28.9 | 29.5 | 1.2 | 1.2 | 1.3 | 1.3 | 3.4 | 4.4 | 3.8 | 3.8 |
| GREEN | 100 | 18.2 | 18.7 | 12.6 | 11.3 | 2.1 | 2.0 | 2.5 | 2.6 | 11.9 | 13.3 | 9.5 | 9.4 |
| BLUE | 100 | 21.3 | 22.7 | 16.9 | 16.3 | 2.1 | 1.3 | 1.1 | 0.7 | 9.1 | 7.5 | 9.4 | 9.1 |
| CMYK | 100 | 14.1 | 14.7 | 1.1 | 1.5 | 1.1 | 1.0 | 0.7 | 0.6 | 0.9 | 1.2 | 1.2 | 0.9 |

**Figure 10 - 50 kLux Polycarbonate Summary of ΔE Samples 13-24 - 224 days**

| Color Patch | | 50 kLux Delta E by Sample Number - 224 days | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Color | % | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| | | | | | | | | | |
| MEDIA | 0 | 2.1 | 2.2 | 1.1 | 1.2 | 1.9 | 1.8 | 1.1 | 1.3 |
| | 0 | 2.0 | 2.2 | 1.2 | 1.2 | 1.8 | 1.8 | 1.3 | 1.3 |
| | 0 | 2.0 | 2.1 | 1.1 | 1.3 | 1.8 | 1.8 | 1.1 | 1.3 |
| | | | | | | | | | |
| BLACK | 10 | 1.7 | 1.6 | 5.0 | 4.8 | 2.6 | 2.5 | 2.1 | 2.3 |
| | 25 | 1.7 | 2.3 | 3.6 | 3.5 | 8.0 | 8.5 | 6.5 | 6.4 |
| | 40 | 2.2 | 2.8 | 5.0 | 5.1 | 15.5 | 15.4 | 10.1 | 9.4 |
| | 50 | 2.5 | 3.0 | 5.1 | 5.3 | 20.8 | 20.0 | 12.8 | 11.5 |
| | 75 | 1.9 | 2.1 | 2.6 | 2.8 | 19.4 | 20.0 | 9.4 | 9.6 |
| | 100 | 0.9 | 1.1 | 1.2 | 1.0 | 27.8 | 26.6 | 6.7 | 7.4 |
| CYAN | 10 | 3.7 | 3.9 | 2.9 | 3.1 | 3.5 | 3.3 | 1.7 | 1.7 |
| | 25 | 4.6 | 4.9 | 4.0 | 4.1 | 6.1 | 6.4 | 2.0 | 2.1 |
| | 40 | 3.7 | 4.3 | 3.4 | 3.4 | 8.1 | 8.4 | 2.2 | 2.3 |
| | 50 | 3.7 | 4.4 | 2.2 | 2.2 | 9.1 | 8.5 | 2.4 | 2.4 |
| | 75 | 3.0 | 4.2 | 1.2 | 1.3 | 10.0 | 10.3 | 2.5 | 2.6 |
| | 100 | 2.2 | 3.0 | 1.5 | 1.6 | 9.2 | 9.1 | 2.8 | 2.9 |
| MAGENTA | 10 | 4.6 | 5.9 | 6.4 | 4.7 | 4.2 | 4.7 | 2.0 | 1.8 |
| | 25 | 7.9 | 7.3 | 7.1 | 5.6 | 9.5 | 10.3 | 2.9 | 2.3 |
| | 40 | 5.9 | 6.8 | 5.9 | 5.6 | 15.2 | 16.4 | 3.0 | 2.8 |
| | 50 | 6.3 | 6.5 | 6.1 | 6.1 | 17.8 | 21.1 | 3.0 | 2.7 |
| | 75 | 4.5 | 3.3 | 2.6 | 2.5 | 17.3 | 17.2 | 10.8 | 7.7 |
| | 100 | 4.1 | 3.7 | 3.9 | 3.3 | 14.7 | 14.1 | 8.9 | 9.4 |
| YELLOW | 10 | 6.5 | 6.7 | 15.2 | 15.0 | 2.1 | 2.4 | 3.4 | 3.1 |
| | 25 | 15.6 | 15.9 | 40.3 | 39.5 | 12.8 | 13.8 | 12.3 | 11.3 |
| | 40 | 17.2 | 17.6 | 52.6 | 54.6 | 25.7 | 27.4 | 18.0 | 17.9 |
| | 50 | 18.7 | 17.5 | 55.9 | 57.0 | 35.8 | 37.7 | 21.4 | 21.7 |
| | 75 | 10.8 | 10.5 | 34.6 | 36.6 | 37.8 | 38.1 | 22.5 | 22.7 |
| | 100 | 4.8 | 5.3 | 4.6 | 4.4 | 34.9 | 35.0 | 19.6 | 20.2 |
| CMY | 10 | 2.0 | 2.4 | 3.9 | 3.6 | 6.0 | 6.7 | 5.2 | 5.1 |
| | 25 | 2.8 | 3.1 | 5.1 | 5.0 | 20.2 | 20.2 | 11.8 | 11.1 |
| | 40 | 1.9 | 1.8 | 1.9 | 2.0 | 18.2 | 18.4 | 8.1 | 8.3 |
| | 50 | 1.0 | 1.0 | 1.1 | 1.1 | 27.6 | 26.4 | 6.4 | 7.9 |
| | 75 | 1.4 | 1.0 | 1.0 | 1.1 | 27.3 | 26.4 | 6.4 | 8.0 |
| | 100 | 1.4 | 0.9 | 1.2 | 1.0 | 27.0 | 27.0 | 6.6 | 8.0 |
| | | | | | | | | | |
| RED | 100 | 3.9 | 5.6 | 6.3 | 4.4 | 24.6 | 22.8 | 7.9 | 8.5 |
| GREEN | 100 | 12.6 | 12.6 | 13.2 | 12.3 | 26.7 | 26.8 | 15.1 | 15.9 |
| BLUE | 100 | 4.4 | 4.0 | 2.9 | 3.0 | 21.5 | 21.2 | 7.5 | 7.0 |
| CMYK | 100 | 1.2 | 1.1 | 1.0 | 1.0 | 25.9 | 26.0 | 6.3 | 7.5 |

**Figure 11 - 50 kLux Polycarbonate Summary of ΔE Samples 25-32 - 224 days**

| Color Patch | | 50 kLux Delta E by Sample Number - 224 days | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Color | % | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
| | | | | | | | | | |
| MEDIA | 0 | 1.7 | 1.5 | 1.9 | 1.7 | 2.9 | 2.6 | 3.0 | 3.0 |
| | 0 | 1.8 | 1.6 | 2.1 | 1.6 | 2.7 | 2.5 | 3.0 | 3.1 |
| | 0 | 1.8 | 2.2 | 2.0 | 1.7 | 2.7 | 2.9 | 3.0 | 3.0 |
| | | | | | | | | | |
| BLACK | 10 | 2.3 | 2.9 | 2.9 | 2.9 | 2.4 | 2.5 | 3.0 | 2.9 |
| | 25 | 12.5 | 13.2 | 7.5 | 9.9 | 2.4 | 2.4 | 3.1 | 3.1 |
| | 40 | 23.4 | 24.3 | 9.2 | 11.9 | 2.5 | 2.7 | 3.3 | 3.3 |
| | 50 | 26.4 | 26.8 | 10.2 | 11.0 | 2.8 | 2.8 | 3.4 | 3.5 |
| | 75 | 23.5 | 24.3 | 12.1 | 11.7 | 2.9 | 3.0 | 2.9 | 2.9 |
| | 100 | 20.2 | 24.0 | 7.3 | 7.4 | 0.5 | 0.3 | 0.6 | 0.4 |
| CYAN | 10 | 3.5 | 3.7 | 3.0 | 2.2 | 2.7 | 2.6 | 3.5 | 3.3 |
| | 25 | 7.2 | 7.2 | 3.6 | 2.8 | 2.7 | 2.7 | 4.2 | 4.0 |
| | 40 | 7.7 | 7.6 | 3.4 | 2.7 | 2.7 | 2.8 | 4.5 | 4.3 |
| | 50 | 9.1 | 9.2 | 3.8 | 3.5 | 2.7 | 3.0 | 4.6 | 4.4 |
| | 75 | 14.5 | 14.8 | 6.0 | 5.4 | 2.8 | 3.1 | 4.0 | 4.1 |
| | 100 | 15.6 | 15.8 | 7.1 | 6.3 | 2.9 | 2.6 | 3.3 | 3.0 |
| MAGENTA | 10 | 3.7 | 4.2 | 8.5 | 6.6 | 5.3 | 5.1 | 5.5 | 5.1 |
| | 25 | 7.5 | 7.3 | 12.9 | 9.4 | 8.3 | 8.3 | 8.0 | 8.0 |
| | 40 | 9.1 | 9.1 | 15.7 | 18.3 | 10.3 | 10.2 | 9.7 | 9.6 |
| | 50 | 13.6 | 13.3 | 13.9 | 10.7 | 11.2 | 10.8 | 10.4 | 10.2 |
| | 75 | 27.0 | 26.9 | 13.9 | 11.4 | 10.4 | 10.4 | 10.0 | 9.9 |
| | 100 | 26.6 | 27.2 | 10.0 | 9.9 | 8.6 | 8.2 | 8.6 | 8.5 |
| YELLOW | 10 | 6.4 | 6.3 | 8.6 | 8.2 | 0.9 | 1.3 | 2.2 | 2.3 |
| | 25 | 20.9 | 21.2 | 23.5 | 21.6 | 0.9 | 0.7 | 0.5 | 0.6 |
| | 40 | 32.3 | 33.1 | 30.4 | 27.6 | 1.8 | 1.7 | 0.8 | 0.7 |
| | 50 | 38.7 | 40.1 | 31.4 | 28.4 | 2.1 | 1.9 | 1.4 | 1.5 |
| | 75 | 55.8 | 57.1 | 28.1 | 27.9 | 2.4 | 2.2 | 2.0 | 1.9 |
| | 100 | 56.7 | 57.9 | 23.5 | 24.1 | 1.0 | 1.1 | 0.9 | 1.0 |
| CMY | 10 | 8.9 | 9.4 | 6.7 | 7.4 | 3.0 | 3.2 | 4.0 | 4.0 |
| | 25 | 25.5 | 26.1 | 10.1 | 10.2 | 3.5 | 3.7 | 4.3 | 4.4 |
| | 40 | 21.7 | 22.1 | 10.5 | 10.4 | 4.4 | 4.3 | 4.3 | 4.4 |
| | 50 | 23.6 | 23.9 | 7.6 | 7.2 | 4.8 | 4.3 | 4.0 | 4.0 |
| | 75 | 23.6 | 23.5 | 7.5 | 7.3 | 3.0 | 3.1 | 1.5 | 1.6 |
| | 100 | 23.1 | 23.6 | 6.7 | 7.6 | 3.0 | 2.3 | 1.6 | 1.3 |
| | | | | | | | | | |
| RED | 100 | 36.7 | 35.9 | 29.7 | 27.6 | 2.6 | 2.7 | 2.6 | 2.8 |
| GREEN | 100 | 21.9 | 22.2 | 8.7 | 8.0 | 0.8 | 1.3 | 1.2 | 1.6 |
| BLUE | 100 | 30.1 | 27.6 | 15.3 | 15.0 | 14.7 | 14.4 | 13.6 | 13.1 |
| CMYK | 100 | 23.5 | 24.2 | 6.7 | 7.3 | 3.5 | 3.2 | 2.4 | 2.4 |

**Figure 12 - 50 kLux Polycarbonate Summary of ΔE Samples 32-40 - 224 days**

## 5.4 Discussion of Accelerated Fluorescent Light Exposure Test Results

Many of the samples reached the defined endpoint of 15 ΔE before the light fade tests were completed. In these tests, the samples were not removed from the exposure but completed the test. They were all measured at each measurement point.

We have summarized these results with the printer/media identities. These summaries are listed below and are in three groups. The first group includes those samples that reached the endpoint by 112 days exposure. The second group includes those samples that had reached the endpoint at the 224 day completion of the test. The final group includes those samples that did not reach the endpoint but survived the complete light fade exposure test.

| *ID* | *Printer* | *Media* |
|---|---|---|
| 1 | Canon iP6600 | Kodak Ultra Prem Photo |
| 2 | Canon iP6600 | Kodak Ultra Prem Photo |
| 3 | Canon iP6600 | Canon Photo Pro |
| 4 | Canon iP6600 | Canon Photo Pro |
| 5 | Canon i9900 | Kodak Ultra Prem Photo |
| 6 | Canon i9900 | Kodak Ultra Prem Photo |
| 7 | Canon i9900 | Canon Photo Pro |
| 8 | Canon i9900 | Canon Photo Pro |
| 9 | Dell A942 | Kodak Ultra Prem Photo |
| 10 | Dell A942 | Kodak Ultra Prem Photo |
| 11 | Dell A942 | Dell Prem Photo Paper |
| 12 | Dell A942 | Dell Prem Photo Paper |
| 13 | Epson R320 | Kodak Ultra Prem Photo |
| 14 | Epson R320 | Kodak Ultra Prem Photo |
| 15 | Epson R320 | Epson Prem Glossy Photo |
| 16 | Epson R320 | Epson Prem Glossy Photo |
| 23 | Epson 2200 | Epson Prem Glossy Photo |
| 24 | Epson 2200 | Epson Prem Glossy Photo |
| 27 | Epson R2400 | Epson Prem Glossy Photo |
| 28 | Epson R2400 | Epson Prem Glossy Photo |
| 31 | HP 8250 | Kodak Ultra Prem Photo |
| 32 | HP 8250 | Kodak Ultra Prem Photo |
| 34 | Lexmark Z816 | Kodak Ultra Prem Photo |
| 35 | Lexmark Z816 | Lexmark Prem Glossy Photo |
| 36 | Lexmark Z816 | Lexmark Prem Glossy Photo |

**Figure 13 - Samples reaching the endpoint at 112 day 50 kLux exposure with Polycarb filtration**

| *ID* | *Printer* | *Media* |
|---|---|---|
| 21 | Epson 2200 | Kodak Ultra Prem Photo |
| 22 | Epson 2200 | Kodak Ultra Prem Photo |
| 25 | Epson R2400 | Kodak Ultra Prem Photo |
| 26 | Epson R2400 | Kodak Ultra Prem Photo |
| 31 | HP 8250 | HP Prem Plus |
| 32 | HP 8250 | HP Prem Plus |
| 33 | Lexmark Z816 | Kodak Ultra Prem Photo |

**Figure 14 - Samples reaching the endpoint by 224 day 50 kLux exposure with Polycarb filtration**

| ID | Printer | Media |
|---|---|---|
| 17 | Epson R800 | Kodak Ultra Prem Photo |
| 18 | Epson R800 | Kodak Ultra Prem Photo |
| 19 | Epson R800 | Epson Prem Glossy Photo |
| 20 | Epson R800 | Epson Prem Glossy Photo |
| 37 | Kodak ES5300 | Kodak Ultra Prem Photo |
| 38 | Kodak ES5300 | Kodak Ultra Prem Photo |
| 39 | Kodak ES5300 | Kodak Ultra Prem Photo |
| 40 | Kodak ES5300 | Kodak Ultra Prem Photo |

**Figure 15 - Samples surviving 224 day 50 kLux exposure with Polycarb filtration**

### 5.4.1 Print Sample Comparison Summary

Although TPR is not using the data to predict print life, we are in a position to compare the prints in terms of expected image stability performance. Based on the results listed above, we have developed a print sample summary. In the test it can be seen that each printer/ink set was tested with two samples of the media, providing a total of 40 samples. In analyzing the results of the light fade test, it is clear that the duplicate media samples behaved as expected, there were no anomalies. Therefore, alternate samples have been omitted from the following table in order to enhance clarity. In addition, the table has been arranged in order of performance, best being at the top of the table.

| ID | Printer | Media | 50 kLux under polycarb | | |
|---|---|---|---|---|---|
| | | | 56 days | 112 days | 224 days |
| 17 | Epson R800 | Kodak Ultra Prem Photo Paper | | | |
| 19 | Epson R800 | Epson Prem Glossy Photo | | | |
| 37 | Kodak ES5300 | Kodak Ultra Prem Photo Paper | | | |
| 39 | Kodak ES5300 | Kodak Ultra Prem Photo Paper | | | |
| 25 | Epson R2400 | Kodak Ultra Prem Photo Paper | | | |
| 21 | Epson 2200 | Kodak Ultra Prem Photo Paper | | | |
| 31 | HP 8250 | HP Prem Plus | | | |
| 11 | Dell A942 | Dell Prem Photo Paper | | | |
| 15 | Epson R320 | Epson Prem Glossy Photo | | | |
| 23 | Epson 2200 | Epson Prem Glossy Photo | | | |
| 27 | Epson R2400 | Epson Prem Glossy Photo | | | |
| 29 | HP 8250 | Kodak Ultra Prem Photo Paper | | | |
| 35 | Lexmark Z816 | Lexmark Prem Glossy Photo | | | |
| 1 | Canon iP6600 | Kodak Ultra Prem Photo Paper | | | |
| 3 | Canon iP6600 | Canon Photo Pro | | | |
| 5 | Canon i9900 | Kodak Ultra Prem Photo Paper | | | |
| 7 | Canon i9900 | Canon Photo Pro | | | |
| 9 | Dell A942 | Kodak Ultra Prem Photo Paper | | | |
| 13 | Epson R320 | Kodak Ultra Prem Photo Paper | | | |
| 33 | Lexmark Z816 | Kodak Ultra Prem Photo Paper | | | |

**Figure 16 – Visual Summary of Light Fade Test Results**

# 6.0 High Humidity Keeping Test

For obvious reasons, inkjet inks and media are carefully formulated so that they are dry to the touch as soon as possible after printing. This is particularly true of the micro porous papers that are now available for most printers.

Some tests have shown that dye based inks used with these media can result in prints that suffer some significant color shift due to humidity effects. Humidity levels as low as 60% can cause these shifts to occur even without the presence of light. The shifts are thought to be due to dye diffusion or migration and de-aggregation in the media. These changes can be referred to as 'dark fastness' rather than humidity effects because they are best tested with light excluded from the prints in order to distinguish the effects from light fade etc.

Ink bleed is another effect that has been reported when prints are exposed to high humidity. This may be manifested as a broadening of a narrow line, wicking from the edge of a solid area, or merging of adjacent colors. In order to assess this effect, the image illustrated in Appendix B was included and submitted to the same high humidity keeping test protocol as the general test image. This image was not printed in duplicate, so the even numbers only were used.

The general test image was measured in the same way as in all of the other image permanence tests. The Appendix B image was measured in a different way. Two prints were made at the beginning of the test, one being reserved as a reference print. The reference print was kept in a dark environment at 23C and 50% RH, the second print was exposed to the 224 day humidity test before being measured. The prints were visually compared in the Gretag-Macbeth Judge II viewing booth using the Artificial Daylight (6500) illumination setting. The visual comparison focused upon bleed, sharpness and color shift.

No definitive standards are available or likely to emerge soon for color bleed, so a subjective and relative assessment was defined by the observer and is used in the results.

## 6.1 Temperature Humidity Chamber

The chamber used for the dark keeping test is a Tenney Benchmaster environmental chamber. This chamber has a capacity of about 4 $ft^3$ and is capable of maintaining temperature in the range 15 °C to 85 °C and humidity in the range 15% to 90%.

## 6.2 Humidity Exposure Test

The temperature and humidity of the chamber were set to 23 °C and 80 % RH respectively and maintained at these levels for the duration of the test.

Prints were removed and measured at the following intervals:

0, 7, 14, 28, 56, 112 and 224 days

### 6.2.1 Humidity Test Color Measurements

These readings were taken on each of the color patches on the sample noted in Appendix A. Samples were removed from their mounting prior to making the measurements.

The values of ΔE for each sample and for most of the color patches are shown in the tables. Values for the lower density patterns of R, B, G and CMYK are omitted for the purpose of conciseness.

Within the tables we have chosen to highlight some of the larger changes by using color fill. The values chosen are based on the criteria developed above and are as follows:

| | | |
|---|---|---|
| 0 to 5 | Change in ΔE | no fill |
| 5.01 to 15 | Change in ΔE | Yellow Fill |
| 15.01 and higher | Change in ΔE | Orange Fill |

| Color Patch | | High Humidity Keeping Delta E by Sample Number | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Color | % | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | | | | | | | | | | | | | |
| MEDIA | 0 | 0.4 | 0.3 | 4.6 | 4.2 | 0.5 | 0.5 | 4.4 | 4.5 | 0.3 | 0.4 | 0.8 | 0.4 |
| | 0 | 0.3 | 0.3 | 4.4 | 3.9 | 0.5 | 0.5 | 4.4 | 4.4 | 0.5 | 0.4 | 0.6 | 0.5 |
| | 0 | 0.4 | 0.2 | 4.2 | 4.1 | 0.5 | 0.7 | 4.1 | 4.4 | 0.4 | 0.3 | 1.8 | 0.7 |
| | | | | | | | | | | | | | |
| BLACK | 10 | 0.4 | 0.4 | 4.3 | 4.2 | 0.4 | 0.4 | 3.6 | 4.0 | 0.9 | 1.1 | 3.2 | 2.9 |
| | 25 | 0.9 | 1.1 | 4.0 | 4.4 | 0.7 | 1.7 | 2.6 | 3.1 | 3.0 | 4.0 | 7.7 | 7.6 |
| | 40 | 1.5 | 1.6 | 3.5 | 4.2 | 1.0 | 3.6 | 1.5 | 2.4 | 3.6 | 6.0 | 7.1 | 11.2 |
| | 50 | 1.9 | 2.0 | 3.2 | 3.7 | 0.6 | 1.8 | 0.8 | 1.7 | 3.3 | 5.6 | 2.5 | 2.6 |
| | 75 | 0.7 | 1.0 | 2.2 | 2.5 | 1.1 | 7.1 | 0.1 | 1.3 | 0.9 | 1.4 | 2.9 | 3.8 |
| | 100 | 1.0 | 1.0 | 0.7 | 0.6 | 2.3 | 4.5 | 0.7 | 0.7 | 1.4 | 0.8 | 0.8 | 5.2 |
| CYAN | 10 | 0.5 | 0.4 | 4.2 | 4.4 | 0.4 | 0.2 | 4.1 | 4.4 | 0.6 | 0.7 | 0.5 | 0.5 |
| | 25 | 0.4 | 0.5 | 4.1 | 4.2 | 0.6 | 0.6 | 4.0 | 4.3 | 0.6 | 0.7 | 0.7 | 0.5 |
| | 40 | 0.6 | 0.6 | 4.1 | 3.9 | 0.9 | 1.3 | 3.9 | 4.1 | 0.5 | 0.3 | 2.7 | 0.5 |
| | 50 | 0.6 | 0.6 | 3.4 | 3.7 | 1.1 | 1.8 | 3.8 | 3.9 | 0.4 | 0.4 | 1.0 | 0.8 |
| | 75 | 0.7 | 0.7 | 3.2 | 3.2 | 1.4 | 1.9 | 3.2 | 3.4 | 0.8 | 0.6 | 1.2 | 1.3 |
| | 100 | 0.7 | 0.7 | 2.5 | 2.6 | 1.4 | 1.9 | 3.4 | 3.2 | 0.8 | 0.7 | 1.6 | 1.4 |
| MAGENTA | 10 | 0.9 | 0.8 | 4.7 | 4.6 | 0.9 | 1.0 | 3.7 | 3.9 | 0.5 | 0.5 | 0.6 | 0.6 |
| | 25 | 2.0 | 2.0 | 4.5 | 4.4 | 0.8 | 1.2 | 2.8 | 3.0 | 0.3 | 0.3 | 1.1 | 1.0 |
| | 40 | 2.8 | 2.8 | 4.1 | 3.9 | 0.7 | 3.1 | 2.1 | 2.1 | 0.3 | 0.5 | 1.0 | 1.2 |
| | 50 | 2.1 | 2.4 | 3.8 | 3.7 | 0.5 | 2.4 | 1.7 | 1.8 | 0.4 | 0.6 | 0.6 | 1.0 |
| | 75 | 2.5 | 3.2 | 2.8 | 2.8 | 0.2 | 1.0 | 0.9 | 0.9 | 2.8 | 4.4 | 3.7 | 4.2 |
| | 100 | 2.4 | 3.5 | 2.3 | 2.3 | 0.5 | 2.7 | 0.7 | 0.6 | 1.0 | 1.1 | 4.1 | 4.7 |
| YELLOW | 10 | 0.3 | 0.4 | 4.4 | 4.0 | 0.5 | 0.8 | 3.7 | 4.6 | 0.8 | 0.9 | 3.5 | 2.7 |
| | 25 | 0.8 | 1.2 | 4.1 | 4.1 | 1.4 | 1.9 | 3.3 | 5.1 | 2.5 | 3.1 | 7.3 | 5.9 |
| | 40 | 1.5 | 1.6 | 4.2 | 4.2 | 1.9 | 3.1 | 2.5 | 4.6 | 3.7 | 4.4 | 9.3 | 8.1 |
| | 50 | 1.7 | 1.8 | 4.0 | 4.0 | 2.0 | 5.9 | 2.0 | 4.1 | 3.9 | 4.9 | 9.8 | 8.6 |
| | 75 | 0.4 | 0.4 | 3.6 | 3.6 | 0.4 | 0.5 | 0.9 | 2.8 | 3.7 | 4.8 | 9.0 | 9.0 |
| | 100 | 0.6 | 1.0 | 2.9 | 2.8 | 1.1 | 4.9 | 0.6 | 1.8 | 2.7 | 3.9 | 7.4 | 7.8 |
| CMY | 10 | 0.6 | 0.7 | 4.1 | 3.9 | 0.6 | 1.3 | 2.8 | 3.4 | 2.4 | 3.3 | 7.3 | 6.1 |
| | 25 | 1.5 | 1.7 | 3.2 | 3.6 | 0.8 | 2.8 | 0.9 | 2.0 | 4.3 | 6.0 | 2.9 | 3.2 |
| | 40 | 1.0 | 1.5 | 1.8 | 1.8 | 1.4 | 7.2 | 0.0 | 0.8 | 0.7 | 2.4 | 3.2 | 2.9 |
| | 50 | 1.0 | 1.2 | 0.5 | 0.4 | 2.3 | 4.4 | 0.8 | 0.7 | 1.1 | 0.8 | 1.2 | 4.5 |
| | 75 | 1.1 | 1.0 | 0.7 | 0.6 | 2.2 | 4.5 | 0.7 | 0.8 | 1.0 | 0.7 | 1.5 | 3.6 |
| | 100 | 0.8 | 1.0 | 0.5 | 0.4 | 2.1 | 4.5 | 0.7 | 0.6 | 1.2 | 1.4 | 2.1 | 1.6 |
| | | | | | | | | | | | | | |
| RED | 100 | 3.7 | 6.2 | 2.3 | 2.5 | 2.8 | 4.6 | 0.6 | 0.7 | 1.4 | 3.1 | 1.4 | 1.7 |
| GREEN | 100 | 2.6 | 3.2 | 0.8 | 1.0 | 4.8 | 10.7 | 1.2 | 0.8 | 2.0 | 2.4 | 1.9 | 1.4 |
| BLUE | 100 | 0.7 | 1.0 | 2.9 | 3.1 | 1.8 | 4.7 | 2.7 | 2.5 | 0.8 | 0.8 | 0.8 | 0.8 |
| CMYK | 100 | 1.2 | 1.1 | 0.5 | 0.5 | 2.3 | 4.5 | 0.7 | 0.5 | 1.2 | 1.2 | 1.2 | 4.5 |

**Figure 17 – High Humidity Keeping Summary of ΔE for Samples 1-12, 224 days Exposure**

| Color Patch | | High Humidity Keeping Delta E by Sample Number | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Color | % | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| MEDIA | 0 | 0.7 | 0.4 | 0.5 | 0.4 | 0.4 | 0.2 | 0.6 | 0.6 | 0.2 | 0.2 | 0.6 | 0.5 |
| | 0 | 0.9 | 0.4 | 0.5 | 0.5 | 0.6 | 0.3 | 0.5 | 0.7 | 0.2 | 0.4 | 0.7 | 0.5 |
| | 0 | 0.8 | 0.4 | 0.5 | 0.5 | 0.5 | 0.3 | 0.6 | 0.5 | 0.2 | 0.2 | 0.7 | 0.4 |
| BLACK | 10 | 0.3 | 0.4 | 1.7 | 2.5 | 1.6 | 1.0 | 0.3 | 0.4 | 0.3 | 0.4 | 0.9 | 0.6 |
| | 25 | 0.3 | 0.3 | 2.1 | 2.1 | 0.7 | 0.7 | 0.5 | 0.4 | 0.2 | 0.9 | 1.4 | 1.3 |
| | 40 | 0.7 | 0.7 | 1.6 | 1.4 | 0.3 | 0.3 | 0.6 | 0.4 | 0.1 | 1.2 | 1.0 | 1.1 |
| | 50 | 1.1 | 1.1 | 2.1 | 1.5 | 0.6 | 0.4 | 0.9 | 0.9 | 0.6 | 1.0 | 1.2 | 1.1 |
| | 75 | 0.9 | 0.5 | 3.6 | 3.3 | 0.6 | 1.3 | 0.6 | 0.7 | 0.9 | 0.9 | 0.9 | 1.0 |
| | 100 | 1.1 | 1.0 | 2.6 | 2.2 | 0.6 | 0.8 | 0.9 | 0.6 | 0.7 | 0.9 | 0.4 | 0.6 |
| CYAN | 10 | 0.7 | 0.8 | 1.2 | 1.2 | 1.2 | 0.7 | 0.7 | 0.6 | 0.5 | 0.5 | 0.8 | 0.6 |
| | 25 | 1.2 | 1.0 | 2.3 | 2.3 | 0.9 | 0.5 | 1.1 | 1.2 | 0.5 | 0.8 | 1.1 | 0.9 |
| | 40 | 1.0 | 1.1 | 3.1 | 3.0 | 0.5 | 0.6 | 1.7 | 1.3 | 0.4 | 0.6 | 1.7 | 1.2 |
| | 50 | 1.1 | 1.0 | 2.8 | 2.7 | 0.1 | 0.4 | 1.5 | 1.4 | 0.2 | 0.7 | 1.7 | 1.5 |
| | 75 | 0.8 | 0.5 | 0.8 | 1.1 | 0.8 | 1.5 | 2.1 | 1.9 | 0.9 | 1.9 | 1.9 | 1.5 |
| | 100 | 0.7 | 0.7 | 1.0 | 1.2 | 1.1 | 2.0 | 1.8 | 1.7 | 0.9 | 1.8 | 1.9 | 1.7 |
| MAGENTA | 10 | 0.6 | 0.6 | 0.4 | 0.3 | 0.3 | 0.5 | 1.0 | 1.0 | 0.1 | 0.3 | 0.9 | 1.0 |
| | 25 | 1.3 | 1.3 | 1.6 | 1.2 | 0.7 | 0.2 | 0.9 | 0.7 | 0.4 | 0.8 | 1.3 | 1.3 |
| | 40 | 1.8 | 1.9 | 1.7 | 1.6 | 1.2 | 0.5 | 0.8 | 0.8 | 0.4 | 0.5 | 1.3 | 1.6 |
| | 50 | 1.8 | 2.2 | 2.0 | 2.4 | 0.7 | 0.5 | 1.0 | 0.8 | 0.8 | 1.0 | 1.5 | 1.6 |
| | 75 | 1.9 | 2.5 | 3.1 | 3.8 | 0.7 | 0.3 | 0.8 | 1.0 | 0.6 | 0.8 | 0.7 | 0.9 |
| | 100 | 1.8 | 3.5 | 2.0 | 2.5 | 0.1 | 0.7 | 1.6 | 1.6 | 1.0 | 0.6 | 0.8 | 1.1 |
| YELLOW | 10 | 0.2 | 0.2 | 3.0 | 3.0 | 0.8 | 0.8 | 0.7 | 0.7 | 0.4 | 0.4 | 0.4 | 0.4 |
| | 25 | 0.4 | 0.2 | 3.2 | 3.3 | 1.2 | 0.7 | 1.6 | 1.4 | 0.6 | 0.4 | 0.7 | 0.6 |
| | 40 | 0.1 | 0.1 | 2.3 | 2.6 | 0.8 | 0.5 | 1.3 | 1.4 | 0.5 | 0.3 | 1.2 | 0.6 |
| | 50 | 0.4 | 0.2 | 1.6 | 1.9 | 0.4 | 0.3 | 0.9 | 1.0 | 0.4 | 0.6 | 1.0 | 1.1 |
| | 75 | 1.0 | 0.3 | 1.5 | 1.3 | 1.5 | 0.7 | 0.7 | 1.1 | 1.0 | 0.5 | 1.5 | 0.8 |
| | 100 | 0.8 | 0.4 | 3.3 | 3.2 | 1.8 | 1.6 | 0.9 | 0.6 | 0.7 | 0.5 | 0.7 | 1.1 |
| CMY | 10 | 0.2 | 0.1 | 2.3 | 2.8 | 1.0 | 0.4 | 0.5 | 0.8 | 0.4 | 0.9 | 1.3 | 1.1 |
| | 25 | 0.8 | 1.2 | 1.7 | 1.4 | 0.6 | 0.6 | 0.9 | 0.7 | 0.5 | 1.0 | 1.2 | 1.2 |
| | 40 | 0.9 | 0.9 | 2.5 | 2.5 | 0.5 | 0.7 | 0.7 | 0.8 | 1.4 | 0.7 | 0.8 | 0.6 |
| | 50 | 1.0 | 1.0 | 2.4 | 2.3 | 0.6 | 0.7 | 0.3 | 0.8 | 0.7 | 1.0 | 0.6 | 0.7 |
| | 75 | 1.1 | 1.1 | 2.5 | 2.3 | 0.8 | 1.1 | 1.0 | 0.6 | 0.8 | 0.8 | 0.6 | 0.6 |
| | 100 | 1.8 | 1.0 | 2.4 | 2.1 | 1.0 | 0.9 | 0.8 | 0.5 | 1.0 | 0.9 | 0.8 | 0.8 |
| RED | 100 | 1.2 | 2.0 | 5.3 | 4.5 | 0.8 | 0.2 | 1.0 | 1.4 | 0.7 | 1.5 | 0.8 | 0.7 |
| GREEN | 100 | 1.2 | 0.7 | 5.0 | 4.8 | 0.8 | 0.9 | 1.6 | 1.5 | 1.5 | 2.6 | 0.7 | 0.7 |
| BLUE | 100 | 1.2 | 0.7 | 0.6 | 1.4 | 0.8 | 1.8 | 2.3 | 2.5 | 0.8 | 0.4 | 0.8 | 0.6 |
| CMYK | 100 | 1.0 | 1.0 | 2.4 | 2.4 | 1.2 | 0.4 | 1.1 | 0.7 | 0.5 | 0.8 | 0.9 | 0.7 |

**Figure 18 - High Humidity Keeping Summary of ΔE for Samples 13-24, 224 days Exposure**

| Color Patch | | High Humidity Keeping Delta E by Sample Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Color | % | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| | | | | | | | | | |
| MEDIA | 0 | 0.4 | 0.2 | 0.7 | 0.7 | 0.2 | 0.3 | 0.2 | 0.2 |
| | 0 | 0.3 | 0.4 | 0.7 | 0.6 | 0.2 | 0.3 | 0.1 | 0.2 |
| | 0 | 0.6 | 0.3 | 0.5 | 0.6 | 0.2 | 0.3 | 0.2 | 0.2 |
| | | | | | | | | | |
| BLACK | 10 | 0.3 | 0.2 | 0.2 | 0.2 | 0.4 | 0.5 | 2.1 | 2.2 |
| | 25 | 0.6 | 0.9 | 1.0 | 1.0 | 0.2 | 0.2 | 5.1 | 5.3 |
| | 40 | 0.7 | 1.1 | 1.3 | 1.4 | 0.8 | 0.9 | 5.7 | 5.9 |
| | 50 | 0.6 | 1.1 | 1.2 | 1.3 | 1.9 | 1.5 | 4.5 | 4.7 |
| | 75 | 0.5 | 0.8 | 1.2 | 0.9 | 0.8 | 1.7 | 1.8 | 1.8 |
| | 100 | 0.4 | 0.4 | 0.4 | 0.6 | 1.8 | 2.5 | 0.6 | 0.7 |
| CYAN | 10 | 0.6 | 0.4 | 0.9 | 0.8 | 0.3 | 0.3 | 0.4 | 0.2 |
| | 25 | 0.8 | 0.7 | 1.5 | 1.3 | 0.2 | 0.3 | 0.6 | 0.5 |
| | 40 | 0.6 | 0.4 | 1.7 | 1.6 | 0.3 | 0.3 | 0.8 | 0.5 |
| | 50 | 0.9 | 1.8 | 1.7 | 1.6 | 0.4 | 0.3 | 0.9 | 0.3 |
| | 75 | 1.5 | 2.7 | 2.1 | 2.1 | 0.6 | 0.7 | 0.4 | 0.3 |
| | 100 | 1.2 | 1.9 | 2.0 | 1.9 | 0.6 | 0.7 | 0.5 | 0.4 |
| MAGENTA | 10 | 0.9 | 0.9 | 0.8 | 0.6 | 0.4 | 0.6 | 1.6 | 1.5 |
| | 25 | 0.7 | 0.7 | 1.0 | 1.0 | 0.7 | 1.1 | 1.5 | 1.4 |
| | 40 | 0.6 | 1.5 | 1.8 | 1.9 | 0.6 | 0.9 | 1.1 | 0.9 |
| | 50 | 0.3 | 1.2 | 1.2 | 1.2 | 0.4 | 0.8 | 0.7 | 0.6 |
| | 75 | 0.3 | 1.9 | 2.3 | 2.4 | 0.5 | 1.7 | 2.4 | 2.0 |
| | 100 | 0.5 | 0.7 | 1.3 | 1.5 | 1.0 | 1.2 | 1.8 | 1.8 |
| YELLOW | 10 | 0.8 | 0.3 | 1.1 | 1.0 | 0.1 | 0.3 | 2.9 | 3.0 |
| | 25 | 1.5 | 1.1 | 1.5 | 1.4 | 0.2 | 0.5 | 6.1 | 6.2 |
| | 40 | 1.1 | 0.8 | 2.0 | 2.1 | 0.2 | 0.5 | 5.8 | 5.8 |
| | 50 | 1.2 | 0.8 | 2.3 | 1.7 | 0.3 | 0.3 | 5.5 | 5.2 |
| | 75 | 1.2 | 1.2 | 1.5 | 1.3 | 0.9 | 1.2 | 4.3 | 3.7 |
| | 100 | 0.6 | 1.0 | 1.1 | 1.6 | 1.6 | 2.5 | 3.1 | 2.9 |
| CMY | 10 | 0.8 | 0.9 | 1.3 | 1.3 | 0.2 | 0.1 | 4.6 | 4.5 |
| | 25 | 0.6 | 1.0 | 1.0 | 0.9 | 1.8 | 1.4 | 4.8 | 5.2 |
| | 40 | 0.4 | 0.6 | 0.6 | 0.8 | 0.8 | 2.0 | 2.0 | 2.1 |
| | 50 | 0.5 | 0.6 | 0.5 | 0.7 | 2.4 | 2.4 | 0.9 | 0.5 |
| | 75 | 0.3 | 0.6 | 0.6 | 0.8 | 2.1 | 2.5 | 0.5 | 0.7 |
| | 100 | 0.4 | 0.5 | 0.5 | 0.6 | 2.5 | 2.4 | 0.5 | 0.9 |
| | | | | | | | | | |
| RED | 100 | 2.4 | 2.1 | 2.1 | 1.1 | 1.5 | 2.9 | 1.4 | 1.5 |
| GREEN | 100 | 1.5 | 2.3 | 1.7 | 2.5 | 1.9 | 2.6 | 1.8 | 2.1 |
| BLUE | 100 | 0.3 | 0.6 | 0.5 | 0.6 | 2.4 | 1.2 | 2.5 | 2.4 |
| CMYK | 100 | 0.4 | 0.6 | 0.8 | 1.0 | 2.3 | 2.3 | 0.3 | 0.5 |

**Figure 19 - High Humidity Keeping Summary of ΔE for Samples 25-32, 224 days Exposure**

| Color Patch | | High Humidity Keeping Delta E by Sample Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Color | % | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
| | | | | | | | | | |
| MEDIA | 0 | 0.3 | 0.2 | 1.7 | 0.5 | 0.4 | 0.1 | 0.6 | 0.5 |
| | 0 | 0.4 | 0.7 | 0.9 | 0.5 | 0.4 | 0.3 | 0.8 | 0.6 |
| | 0 | 0.6 | 0.2 | 1.0 | 0.5 | 0.5 | 0.3 | 0.6 | 0.7 |
| | | | | | | | | | |
| BLACK | 10 | 0.4 | 0.7 | 1.8 | 1.9 | 0.1 | 0.2 | 0.4 | 0.3 |
| | 25 | 3.3 | 1.9 | 5.8 | 5.8 | 0.2 | 0.3 | 0.4 | 0.2 |
| | 40 | 5.6 | 5.7 | 6.6 | 6.3 | 0.2 | 0.4 | 0.4 | 0.2 |
| | 50 | 5.9 | 5.3 | 3.8 | 3.8 | 0.4 | 0.5 | 0.3 | 0.2 |
| | 75 | 2.0 | 4.1 | 2.0 | 1.7 | 0.3 | 0.7 | 0.6 | 0.3 |
| | 100 | 1.9 | 1.4 | 1.5 | 1.2 | 0.7 | 1.4 | 1.2 | 0.4 |
| CYAN | 10 | 0.9 | 0.8 | 0.4 | 0.5 | 0.0 | 0.3 | 0.6 | 0.3 |
| | 25 | 0.7 | 0.5 | 0.7 | 0.8 | 0.5 | 0.5 | 0.6 | 0.3 |
| | 40 | 0.4 | 0.2 | 0.6 | 1.1 | 0.6 | 0.6 | 0.8 | 0.6 |
| | 50 | 0.2 | 0.1 | 0.5 | 0.6 | 0.6 | 0.5 | 0.8 | 0.6 |
| | 75 | 0.7 | 0.8 | 0.4 | 0.3 | 0.5 | 0.6 | 0.7 | 0.6 |
| | 100 | 0.8 | 1.1 | 0.7 | 0.4 | 1.1 | 1.9 | 1.5 | 1.3 |
| MAGENTA | 10 | 0.6 | 0.7 | 0.8 | 0.8 | 0.2 | 0.3 | 0.6 | 0.5 |
| | 25 | 0.2 | 0.6 | 1.8 | 1.5 | 0.3 | 0.5 | 0.6 | 0.6 |
| | 40 | 0.4 | 0.6 | 1.7 | 1.6 | 0.5 | 0.5 | 0.5 | 0.4 |
| | 50 | 1.1 | 1.3 | 1.5 | 2.0 | 0.7 | 0.6 | 0.4 | 0.6 |
| | 75 | 3.8 | 4.6 | 2.4 | 2.6 | 0.6 | 0.6 | 0.4 | 0.3 |
| | 100 | 1.4 | 0.8 | 3.0 | 3.1 | 0.5 | 0.4 | 0.4 | 0.6 |
| YELLOW | 10 | 0.4 | 0.3 | 3.6 | 4.1 | 0.1 | 0.2 | 0.7 | 0.4 |
| | 25 | 2.4 | 1.3 | 7.5 | 8.9 | 0.3 | 0.2 | 0.4 | 0.3 |
| | 40 | 3.9 | 1.9 | 5.9 | 9.3 | 0.7 | 0.5 | 0.3 | 0.2 |
| | 50 | 3.8 | 2.3 | 4.8 | 8.5 | 0.7 | 0.8 | 0.2 | 0.3 |
| | 75 | 4.2 | 2.8 | 3.5 | 5.6 | 0.9 | 1.1 | 0.5 | 0.6 |
| | 100 | 3.7 | 2.1 | 3.8 | 5.2 | 0.8 | 0.9 | 0.5 | 0.5 |
| CMY | 10 | 2.1 | 1.4 | 3.5 | 6.3 | 0.2 | 0.3 | 0.3 | 0.3 |
| | 25 | 5.3 | 5.3 | 3.3 | 6.7 | 0.5 | 0.6 | 0.3 | 0.3 |
| | 40 | 1.5 | 2.7 | 2.3 | 2.2 | 0.4 | 0.7 | 0.4 | 0.2 |
| | 50 | 1.6 | 1.0 | 1.4 | 1.2 | 0.4 | 0.8 | 0.4 | 0.4 |
| | 75 | 1.6 | 0.8 | 1.6 | 1.4 | 0.6 | 1.0 | 0.7 | 0.4 |
| | 100 | 1.6 | 1.3 | 1.4 | 1.3 | 0.7 | 1.7 | 2.2 | 0.5 |
| | | | | | | | | | |
| RED | 100 | 2.2 | 4.3 | 2.3 | 3.3 | 1.0 | 1.3 | 2.1 | 0.4 |
| GREEN | 100 | 2.4 | 2.8 | 1.8 | 1.3 | 0.9 | 0.8 | 0.7 | 0.5 |
| BLUE | 100 | 1.1 | 1.0 | 1.3 | 2.4 | 1.4 | 2.5 | 1.0 | 0.9 |
| CMYK | 100 | 1.4 | 1.0 | 1.1 | 1.0 | 0.4 | 0.3 | 0.3 | 0.8 |

**Figure 20 - High Humidity Keeping Summary of ΔE for Samples 33-40, 224 days Exposure**

### 6.2.2 Humidity Test Visual Results

The most identifiable problem that users would see in reviewing these prints is color bleed. There were several areas of the subject print where this problem could be observed as illustrated in the following photos.


**Figure 21 - Reverse text area of humidity image - white on black**


**Figure 22 - Reverse text area after humidity exposure - ink bleed from black areas into white text**

These photos show that some of the ink used to create the black background has bled into the white or non-imaged text areas and produced a red coloration.

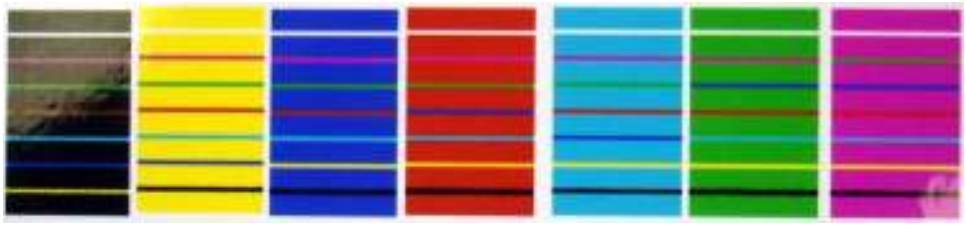

**Figure 23 - Color bleed pattern from original print showing no significant bleed**

**Figure 24 - Color bleed pattern showing easily observable color bleed**

**Figure 25 - Color bleed pattern showing easily observable color bleed**

Patterns such as these are rarely seen in consumer photo images; however the effect of color bleed can also be seen in the pictorial image that is part of the humidity test image. Note in the illustration below the change in overall color caused by humidity exposure might not be noticed without the reference print. However, the red bleed around the black area would probably be noticed.

**Figure 26 – Detail of sample before and after humidity exposure**

To assess these effects each print was visually examined and placed in one of 5 rating categories. All prints are rated on the difference between the room sample, and the exposed sample. If the room sample (not exposed to any conditions), showed moderate color bleed, and the exposed sample showed no further bleed, the sample would be rated as "no visible difference". The 5 rating categories are:

Each print was placed in one of 4 rating categories. All prints are rated on the difference between the room sample, and the exposed sample. If the room sample (not exposed to any conditions), showed moderate color bleed, and the exposed sample showed no further bleed, the sample would be rated as "no visible difference". The 4 rating categories are:

**No Visual Difference (NVD) -** The exposed sample looks identical to the room sample, in all ways

**Slight** - Requires close inspection to see any change between the exposed and the room sample.

**Moderate** – May not be offensive, but does not require close inspection to identify changes.

**Heavy** – Issues may catch the eye immediately when viewing a sample or changes are large, easily identified. Most would be considered failures or unacceptable.

A summary of these subjective assessments is provided in the next table.

| ID | Printer | Media | Issue | Rating | Comments |
|---|---|---|---|---|---|
| 3 | Canon iP6600 | Canon Photo Pro | None | NVD | |
| 7 | Canon i9900 | Canon Photo Pro | None | NVD | |
| 17 | Epson R800 | Kodak Ultra Premium Photo | None | NVD | |
| 19 | Epson R800 | Epson Prem Glossy Photo | None | NVD | |
| 21 | Epson 2200 | Kodak Ultra Premium Photo | None | NVD | |
| 23 | Epson 2200 | Epson Prem Glossy Photo | None | NVD | |
| 25 | Epson R2400 | Kodak Ultra Premium Photo | None | NVD | |
| 27 | Epson R2400 | Epson Prem Glossy Photo | None | NVD | |
| 37 | Kodak ES5300 | Kodak Ultra Premium Photo | None | NVD | |
| 1 | Canon iP6600 | Kodak Ultra Premium Photo | Background Fade | Slight | |
| 13 | Epson R320 | Kodak Ultra Premium Photo | Black Color Bleed | Slight | Black color bleed in black background patches and text |
| | | | Red Color Bleed | Slight | Red bleed in striped color patches. |
| 15 | Epson R320 | Epson Prem Glossy Photo | Black Color Bleed | Slight | Black color bleed in black background patches and text |
| | | | Red Color Bleed | Slight | Red bleed in striped color patches. |
| | | | Blue Color Bleed | Slight | Blue bleed in striped color patches. |
| 31 | HP 8250 | HP Prem Plus | Black Background Bleed | Slight | Black color bleed in black background patches and text |
| | | | Magenta Color Bleed | Slight | Magenta bleed in striped color patches. |
| | | | Red Color Bleed | Slight | Red bleed in striped color patches. |
| 5 | Canon i9900 | Kodak Ultra Premium Photo | Reverse Text Color Bleed | Moderate | Black color bleed in black background patches and text |
| | | | Red Color Bleed | Slight | Red bleed in striped color patches. |
| 35 | Lexmark Z816 | Lexmark Prem Glossy Photo | Yellow Color Bleed | Moderate | Yellow bleed in black backgrounds. |
| | | | Photo Background Fade | Moderate | |
| 33 | Lexmark Z816 | Kodak Ultra Premium Photo | Red Color Bleed | Heavy | Red bleed in black backgrounds. |
| | | | Photo Background Fade | Moderate | Yellowing of photo background. |
| 9 | Dell A942 | Kodak Ultra Premium Photo | Red Color Bleed | Heavy | Magenta bleed into white text |
| | | | Photo Clarity | Moderate | Faces blurry or flush |
| 11 | Dell A942 | Dell Prem Photo Paper | Magenta Color Bleed | Heavy | Magenta bleed in black solids |
| | | | Red Color Bleed | Moderate | Red bleed in striped color patches. |
| | | | Photo Background | Moderate | Green hue in background |
| | | | Photo Clarity | Heavy | Faces blurry or flush, loss of focus |
| 29 | HP 8250 | Kodak Ultra Premium Photo | Magenta Color Bleed | Moderate | Magenta bleed into white text |
| | | | Magenta Color Bleed | Heavy | Magenta bleed in striped color patches |
| | | | Red Color Bleed | Heavy | Red bleed in striped color patches |
| | | | Photo Clarity | Moderate | Loss of focus |

**Figure 27 - Summary of Visual Assessment of Humidity Prints - 224 Days**

Samples have been placed in a given group when at least one category has received the worst rating for that group.

## 6.3 Discussion of High Humidity Keeping Test results

### 6.3.1 Color Change

None of the samples reached the level where the color change alone was completely unacceptable (endpoint) by the end of the 224 day test. Therefore we have not considered the measurements at the earlier test points of 112 days or less. Few of the samples showed easily visible deterioration in color density through dark keeping at high humidity for 224 days. Samples that had changed in any color by more than 9 ΔE were most likely to show visible deterioration to some observers and these included

Canon i9900 printer inks on Kodak Paper

Dell A942 inks on Dell Premium Photo Paper

Lexmark Z816 inks on Lexmark Premium Glossy Photo Paper

It should be noted that without the original print for comparison it is very unlikely that most observers would be able to detect these changes.

### 6.3.2 Visual Assessment

Ink bleed is often an independent stability factor and is not necessarily related to color change. That is, the combinations listed above that showed the most color change with humidity are not necessarily those that showed the most bleed.

Ink bleed can also be a much more easily visible defect than color change. This is in part due to the tendency of the eye to focus upon lines and edges.

In most cases, best bleed results are obtained when the manufacturers recommended media is used with the manufacturer's ink. Comparing the results for the Canon and HP printers in the table demonstrates this. This was not uniformly true. Based on this, the relative performance of the printers was as follows:

No Bleed – Canon iP6600, Canon i9900, Epson R800, Epson 2200, Epson R2400, Kodak ES5300

Slight Bleed – Epson R320, HP 8250

Moderate Bleed – Lexmark Z816

Heavy Bleed – Dell A942

# 7.0 Accelerated Gas Fastness Test

Ozone is a gas that is found in air polluted by industrial exposure. Ozone is a strong oxidizing agent and causes chemical changes in many materials, potentially including dyes and pigments. Ozone has been shown to be one of the reasons for ink jet print fading. Typical very high ozone levels have been shown to be about 0.025 parts per million (ppm) in air.

The RIT Image Permanence Institute carried out a study to develop an atmospheric pollution-aging test for the Paper and Paper Products Committee of the American Society for Testing and Materials. This procedure is used as the basis for the test for ozone exposure in this test suite.

## 7.1 Ozone Chamber

The chamber used for these tests was an Orec Model 500 Test Chamber. This chamber has an internal volume of about 3 $ft^3$. Ozone is generated using a two-arm UV lamp in a forced airflow. The airflow to the lamp is conditioned and the airflow after the lamp is chilled in order to maintain temperature and humidity in the chamber. The chamber is capable of maintaining ozone levels up to about 2.5 parts per million. The ozone controller system is calibrated by the supplier prior to each long-term test.

## 7.2 Ozone Exposure Test

The sample prints were suspended vertically in the chamber with an edge towards the direction of airflow. The viewing port on the chamber is covered with a flap so that the test was carried out in the absence of ambient light.

The chamber ozone level was maintained at 1 ± 0.03 parts per million for the duration of the test. The chamber temperature and humidity was maintained at 23 °C ± 2 °C and 50% RH ± 5% RH

Prints were removed and measured at the following intervals:

0, 7, 21, 35, 56, and 112 days

In some instances prints were removed completely from the test before the 112 day measurement. This occurred when it was found that an earlier measurement showed that the prints were already so deteriorated that further exposure would be meaningless.

This resulted in three groups of results as follows:

- Samples that failed by 35 days
- Samples that failed by 56 days
- Samples that completed the 112 day test

## 7.3 Ozone Test Measurements

These readings were taken on each of the color patches on the sample noted in Appendices A and B. Samples were removed from their mounting prior to making the measurements.

The values of ΔE for each sample and for most of the color patches are shown in the following tables. Values for the lower density patterns of R, B, G and CMYK are omitted here for the purpose of conciseness.

Within the tables we have chosen to highlight some of the larger changes by using color fill. The values chosen are based on the criteria developed above and are as follows:

| | | |
|---|---|---|
| 0 to 5 | Change in ΔE | no fill |
| 5.01 to 15 | Change in ΔE | Yellow Fill |
| 15.01 and higher | Change in ΔE | Orange Fill |

As noted, a number of samples reached the endpoint much earlier than the 112 day measurement. Therefore we have arranged the result tables differently. Instead of simply listing by sample number, we have listed by failure at days of exposure. Therefore, the first two tables list all of the samples that failed after 7 days exposure and so on.

The sample ID for this series is shown in the table below:

| ID | Printer | Ink | Media |
|---|---|---|---|
| 1 | Canon iP6600 | ChromaLife CLI-8 Dye | Kodak Ultra Prem Photo |
| 2 | Canon iP6600 | ChromaLife CLI-8 Dye | Kodak Ultra Prem Photo |
| 3 | Canon iP6600 | ChromaLife CLI-8 Dye | Kodak Ultra Prem Photo |
| 4 | Canon iP6600 | ChromaLife CLI-8 Dye | Canon Photo Pro |
| 5 | Canon i9900 | Canon i9900 Dyes 8C | Kodak Ultra Prem Photo |
| 6 | Canon i9900 | Canon i9900 Dyes 8C | Kodak Ultra Prem Photo |
| 7 | Canon i9900 | Canon i9900 Dyes 8C | Kodak Ultra Prem Photo |
| 8 | Canon i9900 | Canon i9900 Dyes 8C | Canon Photo Pro |
| 9 | Dell A942 | Dell A942 | Kodak Ultra Prem Photo |
| 10 | Dell A942 | Dell A942 | Kodak Ultra Prem Photo |
| 11 | Dell A942 | Dell A942 | Kodak Ultra Prem Photo |
| 12 | Dell A942 | Dell A942 | Dell Prem Photo Paper |
| 13 | Epson R320 | Epson Photo Dyes 6C | Kodak Ultra Prem Photo |
| 14 | Epson R320 | Epson Photo Dyes 6C | Kodak Ultra Prem Photo |
| 15 | Epson R320 | Epson Photo Dyes 6C | Kodak Ultra Prem Photo |
| 16 | Epson R320 | Epson Photo Dyes 6C | Epson Prem Glossy Photo |
| 17 | Epson R800 | Epson UltraChrome Hi Gloss 8C | Kodak Ultra Prem Photo |
| 18 | Epson R800 | Epson UltraChrome Hi Gloss 8C | Kodak Ultra Prem Photo |
| 19 | Epson R800 | Epson UltraChrome Hi Gloss 8C | Kodak Ultra Prem Photo |
| 20 | Epson R800 | Epson UltraChrome Hi Gloss 8C | Epson Prem Glossy Photo |
| 21 | Epson 2200 | Epson UltraChrome 7C | Kodak Ultra Prem Photo |
| 22 | Epson 2200 | Epson UltraChrome 7C | Kodak Ultra Prem Photo |
| 23 | Epson 2200 | Epson UltraChrome 7C | Kodak Ultra Prem Photo |
| 24 | Epson 2200 | Epson UltraChrome 7C | Epson Prem Glossy Photo |
| 25 | Epson R2400 | Epson UltraChrome K3 8C | Kodak Ultra Prem Photo |
| 26 | Epson R2400 | Epson UltraChrome K3 8C | Kodak Ultra Prem Photo |
| 27 | Epson R2400 | Epson UltraChrome K3 8C | Kodak Ultra Prem Photo |
| 28 | Epson R2400 | Epson UltraChrome K3 8C | Epson Prem Glossy Photo |
| 29 | HP 8250 | HP Vivera 02 Tanks | Kodak Ultra Prem Photo |
| 30 | HP 8250 | HP Vivera 02 Tanks | Kodak Ultra Prem Photo |
| 31 | HP 8250 | HP Vivera 02 Tanks | Kodak Ultra Prem Photo |
| 32 | HP 8250 | HP Vivera 02 Tanks | HP Prem Plus |
| 33 | Lexmark Z816 | #31 Photo, #33/#35 Color 6C | Kodak Ultra Prem Photo |
| 34 | Lexmark Z816 | #31 Photo, #33/#35 Color 6C | Kodak Ultra Prem Photo |
| 35 | Lexmark Z816 | #31 Photo, #33/#35 Color 6C | Kodak Ultra Prem Photo |
| 36 | Lexmark Z816 | #31 Photo, #33/#35 Color 6C | Lexmark Prem Glossy Photo |
| 37 | Kodak ES5300 | Kodak ink cartridges | Kodak Ultra Prem Photo |
| 38 | Kodak ES5300 | Kodak ink cartridges | Kodak Ultra Prem Photo |
| 39 | Kodak ES5300 | Kodak ink cartridges | Kodak Ultra Prem Photo |
| 40 | Kodak ES5300 | Kodak ink cartridges | Kodak Ultra Prem Photo |

**Figure 28 - Ozone Test Sample ID**

| Color Patch | | 1 ppm Ozone Exposure Delta E By Sample Number - 7 days | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Color | % | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 13 |
| | | | | | | | | | | | | | |
| MEDIA | 0 | 0.77 | 2.54 | 0.86 | 0.83 | 0.75 | 2.53 | 2.45 | 0.73 | 0.52 | 2.31 | 0.32 | 0.48 |
| | 0 | 0.55 | 2.53 | 0.68 | 0.77 | 0.64 | 2.85 | 1.92 | 0.82 | 0.66 | 2.42 | 0.86 | 0.65 |
| | 0 | 0.59 | 2.45 | 0.87 | 0.83 | 0.69 | 2.08 | 1.89 | 0.92 | 0.34 | 2.53 | 0.74 | 0.30 |
| | | | | | | | | | | | | | |
| BLACK | 10 | 3.62 | 4.69 | 4.27 | 4.09 | 8.29 | 9.31 | 8.12 | 6.81 | 0.71 | 2.56 | 1.24 | 8.31 |
| | 25 | 6.75 | 5.77 | 7.43 | 6.39 | 17.07 | 17.75 | 15.35 | 14.00 | 2.60 | 1.20 | 1.68 | 10.86 |
| | 40 | 10.16 | 8.41 | 10.09 | 9.51 | 23.21 | 26.07 | 21.80 | 18.91 | 6.82 | 4.40 | 4.61 | 12.42 |
| | 50 | 12.05 | 9.88 | 11.35 | 11.30 | 26.91 | 31.61 | 26.51 | 22.12 | 9.09 | 7.76 | 8.05 | 16.58 |
| | 75 | 13.75 | 12.35 | 12.19 | 13.29 | 33.27 | 40.27 | 37.08 | 31.89 | 14.08 | 18.90 | 32.98 | 6.24 |
| | 100 | 10.65 | 15.43 | 13.59 | 24.95 | 14.28 | 28.44 | 23.64 | 49.07 | 37.89 | 59.11 | 60.94 | 4.40 |
| CYAN | 10 | 6.87 | 5.84 | 5.89 | 8.12 | 12.06 | 12.12 | 11.49 | 10.93 | 2.08 | 3.50 | 2.56 | 7.96 |
| | 25 | 12.18 | 9.84 | 11.16 | 13.27 | 23.33 | 24.24 | 22.91 | 21.52 | 3.69 | 4.71 | 4.70 | 12.49 |
| | 40 | 15.90 | 12.85 | 15.08 | 15.85 | 30.95 | 34.62 | 30.11 | 26.99 | 3.99 | 5.65 | 5.85 | 13.08 |
| | 50 | 15.86 | 13.91 | 15.32 | 14.55 | 30.50 | 40.95 | 31.78 | 28.08 | 5.90 | 7.16 | 8.81 | 12.10 |
| | 75 | 12.96 | 15.20 | 12.71 | 12.04 | 28.36 | 32.24 | 30.98 | 31.17 | 17.41 | 17.48 | 19.53 | 13.26 |
| | 100 | 16.37 | 17.43 | 14.57 | 15.34 | 31.57 | 35.08 | 34.98 | 36.93 | 28.58 | 28.45 | 23.85 | 24.17 |
| MAGENTA | 10 | 6.24 | 8.28 | 8.17 | 6.31 | 13.08 | 14.56 | 14.16 | 11.78 | 2.00 | 3.48 | 2.24 | 7.74 |
| | 25 | 13.47 | 16.72 | 17.28 | 13.10 | 26.25 | 25.28 | 27.92 | 23.72 | 3.97 | 5.04 | 4.16 | 16.27 |
| | 40 | 15.16 | 19.33 | 20.11 | 16.88 | 34.89 | 29.74 | 35.40 | 31.18 | 4.74 | 6.28 | 5.33 | 21.23 |
| | 50 | 14.45 | 19.42 | 18.81 | 18.21 | 37.24 | 28.71 | 38.83 | 37.21 | 5.00 | 6.32 | 7.64 | 21.20 |
| | 75 | 11.05 | 12.26 | 12.65 | 15.65 | 26.73 | 26.95 | 27.13 | 33.93 | 9.34 | 9.77 | 27.41 | 14.24 |
| | 100 | 9.48 | 10.32 | 11.20 | 12.82 | 19.54 | 21.80 | 19.98 | 26.33 | 15.64 | 14.78 | 31.92 | 8.68 |
| YELLOW | 10 | 5.33 | 3.02 | 5.33 | 5.45 | 6.90 | 3.41 | 5.23 | 7.18 | 4.03 | 1.57 | 3.19 | 2.76 |
| | 25 | 15.11 | 11.59 | 13.59 | 13.93 | 14.87 | 12.35 | 15.41 | 16.27 | 11.10 | 7.77 | 9.13 | 8.21 |
| | 40 | 24.80 | 19.59 | 21.74 | 21.08 | 23.26 | 20.24 | 25.32 | 23.72 | 18.91 | 14.18 | 15.34 | 12.63 |
| | 50 | 31.07 | 23.61 | 26.90 | 25.37 | 29.48 | 24.71 | 32.63 | 29.25 | 23.90 | 18.80 | 19.64 | 13.69 |
| | 75 | 40.16 | 30.78 | 34.87 | 31.61 | 35.16 | 31.02 | 33.89 | 32.58 | 35.03 | 26.62 | 26.43 | 16.77 |
| | 100 | 34.53 | 26.10 | 29.32 | 29.86 | 30.63 | 26.29 | 26.71 | 27.32 | 38.99 | 28.61 | 27.54 | 16.63 |
| CMY | 10 | 5.40 | 5.25 | 5.86 | 5.27 | 13.85 | 15.34 | 13.23 | 12.05 | 1.82 | 1.24 | 1.22 | 9.72 |
| | 25 | 11.71 | 25.07 | 28.54 | 29.45 | 55.86 | 41.77 | 37.34 | 57.13 | 18.57 | 17.39 | 13.58 | 36.75 |
| | 40 | 13.51 | 26.01 | 29.22 | 36.29 | 28.28 | 58.66 | 57.66 | 28.45 | 35.77 | 35.97 | 48.35 | 14.42 |
| | 50 | 10.61 | 34.10 | 44.02 | 70.62 | 13.29 | 47.31 | 49.32 | 10.77 | 65.57 | 67.97 | 71.37 | 13.91 |
| | 75 | 10.53 | 33.72 | 43.69 | 70.40 | 13.17 | 45.16 | 48.89 | 10.95 | 65.99 | 68.77 | 70.95 | 13.76 |
| | 100 | 10.55 | 33.56 | 43.95 | 70.61 | 12.91 | 42.55 | 48.97 | 10.85 | 65.85 | 67.83 | 70.51 | 14.13 |
| | | | | | | | | | | | | | |
| RED | 100 | 15.07 | 14.10 | 14.12 | 15.11 | 24.41 | 35.45 | 24.94 | 31.99 | 36.53 | 33.24 | 42.88 | 11.59 |
| GREEN | 100 | 18.55 | 14.15 | 16.07 | 17.82 | 17.68 | 21.03 | 22.45 | 24.50 | 27.86 | 22.71 | 23.54 | 17.71 |
| BLUE | 100 | 23.57 | 22.93 | 24.76 | 25.56 | 51.37 | 52.59 | 50.83 | 57.81 | 16.59 | 15.67 | 37.80 | 26.78 |
| CMYK | 100 | 10.46 | 15.23 | 13.73 | 24.65 | 13.82 | 27.86 | 25.57 | 49.56 | 36.94 | 59.57 | 61.44 | 4.05 |

**Figure 29 – 1 pm Ozone Samples that Failed After 7 Days**

| Color Patch | | 1 ppm Ozone Exposure Delta E By Sample Number - 7 days | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Color | % | 14 | 15 | 16 | 29 | 30 | 31 | | |
| | | | | | | | | | |
| MEDIA | 0 | 2.46 | 1.20 | 0.17 | 0.44 | 0.70 | 0.28 | | |
| | 0 | 2.46 | 0.85 | 0.38 | 0.62 | 2.64 | 0.32 | | |
| | 0 | 2.53 | 0.93 | 0.06 | 0.90 | 2.67 | 1.90 | | |
| | | | | | | | | | |
| BLACK | 10 | 10.97 | 11.23 | 4.29 | 0.66 | 2.63 | 2.06 | | |
| | 25 | 13.25 | 13.54 | 6.77 | 3.10 | 1.23 | 1.60 | | |
| | 40 | 15.92 | 14.82 | 10.33 | 8.17 | 5.68 | 5.89 | | |
| | 50 | 22.88 | 20.83 | 22.33 | 11.12 | 9.50 | 10.20 | | |
| | 75 | 14.54 | 13.50 | 7.51 | 13.45 | 19.55 | 25.65 | | |
| | 100 | 8.96 | 6.38 | 1.48 | 36.26 | 50.88 | 64.84 | | |
| CYAN | 10 | 10.73 | 10.12 | 6.09 | 1.79 | 3.50 | 3.26 | | |
| | 25 | 15.98 | 15.77 | 9.07 | 3.09 | 4.57 | 5.24 | | |
| | 40 | 16.33 | 16.33 | 10.00 | 3.85 | 5.16 | 5.93 | | |
| | 50 | 15.33 | 14.98 | 8.79 | 3.71 | 5.55 | 6.88 | | |
| | 75 | 20.17 | 19.71 | 11.72 | 16.09 | 18.52 | 23.08 | | |
| | 100 | 38.17 | 35.30 | 28.39 | 28.73 | 30.60 | 37.49 | | |
| MAGENTA | 10 | 12.30 | 11.37 | 3.29 | 1.58 | 4.00 | 3.28 | | |
| | 25 | 21.54 | 21.06 | 6.73 | 2.98 | 4.75 | 4.68 | | |
| | 40 | 25.09 | 24.30 | 9.71 | 3.81 | 5.37 | 5.53 | | |
| | 50 | 23.60 | 22.68 | 10.85 | 3.83 | 5.64 | 4.99 | | |
| | 75 | 14.99 | 14.06 | 10.79 | 7.58 | 9.43 | 11.09 | | |
| | 100 | 9.54 | 8.82 | 6.94 | 12.76 | 13.84 | 17.84 | | |
| YELLOW | 10 | 1.67 | 1.97 | 2.38 | 5.44 | 2.80 | 4.63 | | |
| | 25 | 8.86 | 6.88 | 6.19 | 13.38 | 9.51 | 10.78 | | |
| | 40 | 14.32 | 11.15 | 8.85 | 21.55 | 15.60 | 17.57 | | |
| | 50 | 16.03 | 12.94 | 9.71 | 27.13 | 19.06 | 22.19 | | |
| | 75 | 17.77 | 13.46 | 11.04 | 36.79 | 24.19 | 30.32 | | |
| | 100 | 17.27 | 11.23 | 10.23 | 39.08 | 24.55 | 30.96 | | |
| CMY | 10 | 13.12 | 12.99 | 5.16 | 1.40 | 1.30 | 1.42 | | |
| | 25 | 22.54 | 38.34 | 38.61 | 19.99 | 22.85 | 20.17 | | |
| | 40 | 9.91 | 19.26 | 13.30 | 32.27 | 34.56 | 40.65 | | |
| | 50 | 7.85 | 14.46 | 7.79 | 67.85 | 68.18 | 77.00 | | |
| | 75 | 7.76 | 14.19 | 8.19 | 67.74 | 68.04 | 77.05 | | |
| | 100 | 7.47 | 14.01 | 10.34 | 67.96 | 67.63 | 76.90 | | |
| | | | | | | | | | |
| RED | 100 | 14.91 | 12.87 | 10.55 | 32.45 | 31.51 | 40.52 | | |
| GREEN | 100 | 17.53 | 16.24 | 28.63 | 26.33 | 20.37 | 24.58 | | |
| BLUE | 100 | 31.46 | 33.67 | 38.14 | 16.72 | 16.86 | 27.56 | | |
| CMYK | 100 | 8.36 | 5.93 | 1.37 | 35.33 | 53.65 | 64.16 | | |

**Figure 30 – 1 ppm Ozone Summary Additional Samples that Failed After 7 Days**

| Color Patch | | 1 ppm Ozone Exposure Delta E By Sample Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 21 Days | | 35 Days | | | | | | | |
| Color | % | 22 | 24 | 19 | 21 | 28 | | | | | |
| | | | | | | | | | | | |
| MEDIA | 0 | 2.76 | 0.42 | 2.63 | 2.15 | 0.57 | | | | | |
| | 0 | 2.83 | 0.55 | 2.46 | 1.97 | 0.42 | | | | | |
| | 0 | 2.90 | 0.89 | 2.38 | 2.07 | 0.43 | | | | | |
| | | | | | | | | | | | |
| BLACK | 10 | 6.16 | 5.88 | 6.07 | 10.18 | 3.73 | | | | | |
| | 25 | 8.78 | 7.48 | 8.14 | 12.07 | 2.95 | | | | | |
| | 40 | 7.96 | 6.17 | 9.01 | 8.28 | 2.30 | | | | | |
| | 50 | 6.22 | 4.13 | 8.05 | 4.72 | 2.10 | | | | | |
| | 75 | 1.32 | 1.27 | 1.89 | 1.36 | 1.10 | | | | | |
| | 100 | 0.67 | 0.16 | 0.45 | 0.84 | 0.29 | | | | | |
| CYAN | 10 | 5.91 | 7.28 | 5.99 | 11.77 | 12.37 | | | | | |
| | 25 | 9.29 | 10.30 | 9.04 | 18.89 | 16.90 | | | | | |
| | 40 | 10.89 | 11.50 | 9.89 | 19.80 | 15.24 | | | | | |
| | 50 | 11.96 | 10.53 | 10.14 | 17.17 | 10.56 | | | | | |
| | 75 | 11.16 | 8.02 | 14.56 | 9.55 | 2.84 | | | | | |
| | 100 | 20.46 | 16.49 | 15.62 | 15.01 | 3.83 | | | | | |
| MAGENTA | 10 | 5.14 | 3.29 | 5.75 | 5.89 | 10.50 | | | | | |
| | 25 | 7.96 | 5.23 | 9.30 | 9.05 | 8.51 | | | | | |
| | 40 | 9.81 | 9.38 | 10.49 | 10.22 | 9.83 | | | | | |
| | 50 | 11.57 | 8.47 | 10.47 | 10.62 | 10.60 | | | | | |
| | 75 | 9.51 | 7.19 | 9.45 | 7.85 | 2.88 | | | | | |
| | 100 | 3.97 | 4.45 | 5.60 | 6.96 | 0.92 | | | | | |
| YELLOW | 10 | 2.41 | 0.61 | 0.88 | 1.37 | 1.80 | | | | | |
| | 25 | 1.57 | 0.97 | 1.93 | 0.53 | 4.08 | | | | | |
| | 40 | 0.56 | 1.59 | 2.17 | 1.17 | 4.86 | | | | | |
| | 50 | 0.35 | 1.79 | 1.36 | 1.73 | 4.29 | | | | | |
| | 75 | 1.33 | 1.54 | 0.58 | 1.88 | 1.84 | | | | | |
| | 100 | 0.27 | 0.37 | 0.93 | 0.58 | 0.94 | | | | | |
| CMY | 10 | 7.95 | 6.53 | 7.67 | 11.65 | 5.84 | | | | | |
| | 25 | 6.24 | 4.07 | 7.94 | 4.80 | 1.87 | | | | | |
| | 40 | 0.60 | 0.96 | 1.30 | 0.79 | 0.76 | | | | | |
| | 50 | 0.11 | 0.05 | 0.46 | 0.58 | 0.15 | | | | | |
| | 75 | 0.34 | 0.17 | 0.80 | 0.61 | 0.23 | | | | | |
| | 100 | 0.27 | 0.19 | 0.60 | 0.37 | 0.31 | | | | | |
| | | | | | | | | | | | |
| RED | 100 | 2.14 | 1.62 | 2.05 | 2.44 | 0.73 | | | | | |
| GREEN | 100 | 2.25 | 3.63 | 3.66 | 2.11 | 1.20 | | | | | |
| BLUE | 100 | 5.60 | 10.72 | 5.00 | 8.49 | 3.16 | | | | | |
| CMYK | 100 | 0.31 | 0.25 | 0.53 | 0.50 | 0.46 | | | | | |

**Figure 31 - 1 ppm Ozone Summary of Samples that Failed After 21 or 35 Days**

| Color Patch | | 1 ppm Ozone Exposure Delta E By Sample Number - 56 days | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Color | % | 12 | 17 | 18 | 23 | 25 | 26 | 27 | 35 | 36 |
| | | | | | | | | | | |
| MEDIA | 0 | 0.19 | 1.64 | 2.63 | 3.49 | 1.63 | 3.31 | 1.27 | 3.29 | 3.25 |
| | 0 | 1.12 | 1.66 | 2.95 | 2.99 | 1.73 | 2.95 | 1.25 | 3.20 | 3.02 |
| | 0 | 0.59 | 1.62 | 2.73 | 2.92 | 1.54 | 3.08 | 1.25 | 3.30 | 3.09 |
| | | | | | | | | | | |
| BLACK | 10 | 1.14 | 6.13 | 8.23 | 7.71 | 6.15 | 6.81 | 5.72 | 3.53 | 3.50 |
| | 25 | 1.29 | 8.52 | 8.45 | 12.39 | 6.09 | 6.74 | 7.77 | 3.60 | 3.55 |
| | 40 | 1.64 | 8.95 | 9.16 | 11.82 | 6.19 | 5.56 | 7.93 | 3.49 | 3.38 |
| | 50 | 2.21 | 8.15 | 6.24 | 9.32 | 5.46 | 4.39 | 8.01 | 3.23 | 3.18 |
| | 75 | 7.31 | 3.14 | 1.55 | 3.06 | 3.41 | 2.44 | 5.15 | 2.53 | 2.41 |
| | 100 | 8.35 | 1.41 | 0.62 | 0.99 | 0.98 | 0.59 | 1.39 | 1.27 | 1.59 |
| CYAN | 10 | 2.53 | 6.52 | 8.65 | 9.66 | 14.17 | 10.60 | 11.34 | 8.74 | 8.20 |
| | 25 | 3.35 | 9.94 | 12.42 | 16.44 | 17.24 | 16.58 | 17.04 | 14.16 | 12.95 |
| | 40 | 4.05 | 12.19 | 13.62 | 18.16 | 15.21 | 16.31 | 17.20 | 16.46 | 15.16 |
| | 50 | 5.46 | 12.67 | 13.28 | 18.25 | 13.34 | 15.15 | 16.84 | 16.61 | 15.67 |
| | 75 | 9.01 | 13.85 | 15.71 | 14.88 | 12.74 | 12.16 | 16.13 | 15.24 | 14.86 |
| | 100 | 9.93 | 16.39 | 14.91 | 16.21 | 11.50 | 6.50 | 12.07 | 11.65 | 11.63 |
| MAGENTA | 10 | 1.63 | 4.37 | 8.04 | 6.90 | 6.91 | 8.74 | 7.74 | 6.11 | 5.90 |
| | 25 | 2.49 | 7.86 | 12.05 | 10.02 | 10.06 | 12.90 | 11.87 | 9.62 | 9.05 |
| | 40 | 3.06 | 10.33 | 12.82 | 13.15 | 11.24 | 14.27 | 13.94 | 11.71 | 10.88 |
| | 50 | 3.31 | 10.84 | 11.95 | 15.44 | 11.85 | 12.22 | 14.66 | 11.99 | 11.48 |
| | 75 | 6.05 | 10.17 | 8.08 | 13.50 | 8.30 | 3.89 | 8.15 | 8.67 | 8.88 |
| | 100 | 6.99 | 6.33 | 2.51 | 4.93 | 5.98 | 1.39 | 3.93 | 5.27 | 5.12 |
| YELLOW | 10 | 1.66 | 0.87 | 0.80 | 2.20 | 0.54 | 1.23 | 0.42 | 0.75 | 0.68 |
| | 25 | 3.94 | 2.57 | 3.79 | 1.12 | 3.17 | 2.17 | 3.24 | 1.70 | 1.72 |
| | 40 | 6.03 | 2.75 | 2.71 | 0.89 | 4.22 | 3.70 | 4.37 | 3.36 | 2.71 |
| | 50 | 6.90 | 1.90 | 1.42 | 1.61 | 4.30 | 2.54 | 4.69 | 4.01 | 3.39 |
| | 75 | 7.51 | 0.93 | 0.22 | 2.51 | 2.22 | 1.29 | 3.05 | 4.33 | 3.85 |
| | 100 | 7.40 | 1.87 | 0.42 | 0.66 | 1.45 | 1.13 | 1.61 | 1.44 | 2.01 |
| CMY | 10 | 1.36 | 7.41 | 8.59 | 11.75 | 6.18 | 7.53 | 7.57 | 5.15 | 5.50 |
| | 25 | 2.27 | 8.31 | 5.58 | 8.16 | 5.27 | 4.49 | 8.24 | 5.56 | 5.40 |
| | 40 | 6.78 | 2.18 | 1.04 | 1.84 | 2.62 | 1.77 | 3.83 | 4.66 | 4.67 |
| | 50 | 7.09 | 0.93 | 0.63 | 1.22 | 0.65 | 0.62 | 1.21 | 3.53 | 3.40 |
| | 75 | 7.17 | 0.84 | 0.48 | 0.78 | 0.61 | 0.71 | 1.31 | 0.97 | 1.03 |
| | 100 | 7.22 | 0.60 | 0.51 | 0.92 | 0.60 | 0.62 | 0.98 | 1.13 | 0.66 |
| | | | | | | | | | | |
| RED | 100 | 1.95 | 2.11 | 1.79 | 2.28 | 1.66 | 0.99 | 1.07 | 1.17 | 0.98 |
| GREEN | 100 | 6.09 | 2.96 | 1.10 | 1.66 | 0.84 | 1.86 | 1.06 | 4.06 | 4.39 |
| BLUE | 100 | 15.28 | 11.52 | 3.25 | 6.84 | 6.90 | 2.68 | 5.42 | 4.64 | 5.14 |
| CMYK | 100 | 7.62 | 0.79 | 0.47 | 1.10 | 1.28 | 0.57 | 1.45 | 2.60 | 2.04 |

**Figure 32 - 1 ppm Ozone Summary of Samples that Failed After 56 Days**

| Color Patch | | 1 ppm Ozone Exposure Delta E By Sample Number - 112 days | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Failed | | | | | | | Unfailed |
| Color | % | 20 | 33 | 34 | 37 | 38 | 39 | 40 | 32 |
| | | | | | | | | | |
| MEDIA | 0 | 3.25 | 3.38 | 3.40 | 5.12 | 5.25 | 4.97 | 3.14 | 0.23 |
| | 0 | 3.41 | 3.60 | 3.35 | 5.25 | 5.81 | 5.16 | 3.16 | 2.34 |
| | 0 | 3.24 | 3.24 | 3.27 | 5.34 | 5.57 | 5.01 | 3.39 | 1.96 |
| | | | | | | | | | |
| BLACK | 10 | 8.29 | 3.93 | 3.86 | 5.31 | 5.31 | 5.12 | 5.23 | 3.13 |
| | 25 | 10.84 | 4.51 | 4.34 | 5.58 | 5.63 | 5.50 | 5.93 | 2.77 |
| | 40 | 10.42 | 5.08 | 4.88 | 5.91 | 5.88 | 5.85 | 7.03 | 4.09 |
| | 50 | 6.89 | 5.26 | 5.14 | 5.97 | 6.05 | 6.05 | 8.08 | 4.38 |
| | 75 | 2.60 | 5.41 | 5.42 | 6.10 | 6.15 | 6.14 | 11.46 | 3.30 |
| | 100 | 1.08 | 3.99 | 4.26 | 1.76 | 2.99 | 2.62 | 4.55 | 5.96 |
| CYAN | 10 | 15.17 | 6.80 | 6.39 | 8.46 | 8.13 | 8.12 | 8.26 | 4.68 |
| | 25 | 24.06 | 10.44 | 10.34 | 12.37 | 11.99 | 11.93 | 12.28 | 6.16 |
| | 40 | 28.68 | 13.38 | 13.09 | 15.07 | 14.89 | 14.80 | 15.34 | 7.15 |
| | 50 | 30.07 | 14.87 | 14.86 | 16.72 | 16.40 | 16.20 | 16.59 | 7.66 |
| | 75 | 20.81 | 17.11 | 17.27 | 18.29 | 18.30 | 18.27 | 18.21 | 11.35 |
| | 100 | 11.30 | 14.67 | 14.55 | 13.36 | 13.60 | 13.38 | 12.54 | 13.58 |
| MAGENTA | 10 | 6.01 | 6.33 | 6.24 | 8.62 | 8.66 | 8.55 | 7.81 | 3.36 |
| | 25 | 10.07 | 10.43 | 10.29 | 13.04 | 13.04 | 12.91 | 12.30 | 9.96 |
| | 40 | 12.92 | 13.42 | 13.29 | 16.18 | 15.96 | 16.08 | 15.55 | 6.22 |
| | 50 | 13.75 | 14.65 | 14.51 | 16.88 | 16.91 | 16.78 | 16.29 | 4.25 |
| | 75 | 10.41 | 12.71 | 12.54 | 12.51 | 12.96 | 12.54 | 9.96 | 4.46 |
| | 100 | 2.94 | 7.71 | 7.36 | 4.03 | 4.46 | 4.88 | 3.64 | 4.02 |
| YELLOW | 10 | 3.93 | 1.42 | 1.60 | 3.63 | 3.76 | 3.74 | 0.38 | 3.31 |
| | 25 | 12.54 | 2.71 | 2.30 | 1.66 | 1.60 | 1.71 | 3.90 | 8.10 |
| | 40 | 11.13 | 4.57 | 4.25 | 4.95 | 5.08 | 4.86 | 6.68 | 10.21 |
| | 50 | 7.36 | 5.77 | 5.28 | 6.60 | 6.68 | 6.49 | 7.44 | 10.73 |
| | 75 | 1.56 | 6.61 | 7.08 | 8.55 | 8.79 | 8.54 | 7.23 | 11.00 |
| | 100 | 1.15 | 3.88 | 3.99 | 2.87 | 3.18 | 3.95 | 2.23 | 9.45 |
| CMY | 10 | 9.34 | 6.06 | 6.12 | 8.49 | 8.57 | 8.47 | 6.64 | 1.29 |
| | 25 | 7.17 | 7.70 | 7.58 | 8.53 | 8.67 | 8.59 | 8.75 | 2.73 |
| | 40 | 2.27 | 8.01 | 7.78 | 7.91 | 8.10 | 7.96 | 8.12 | 2.88 |
| | 50 | 1.30 | 6.70 | 6.58 | 6.74 | 6.66 | 6.55 | 6.76 | 5.20 |
| | 75 | 0.88 | 4.34 | 5.55 | 2.59 | 2.67 | 3.01 | 3.04 | 4.68 |
| | 100 | 1.05 | 4.88 | 5.59 | 2.60 | 2.59 | 4.00 | 1.67 | 3.98 |
| | | | | | | | | | |
| RED | 100 | 3.04 | 3.63 | 4.56 | 1.16 | 0.92 | 0.92 | 1.36 | 4.12 |
| GREEN | 100 | 3.62 | 6.60 | 7.51 | 3.68 | 4.98 | 4.92 | 3.58 | 7.93 |
| BLUE | 100 | 3.24 | 11.91 | 12.12 | 5.12 | 7.64 | 5.24 | 8.25 | 14.80 |
| CMYK | 100 | 1.30 | 5.03 | 5.37 | 2.76 | 2.58 | 2.98 | 3.17 | 5.57 |

**Figure 33 - 1 ppm Ozone Summary of ΔE for Samples that Reached 112 Days**

## 7.4 Discussion of Test Results

This test had the most effects upon the samples. 45% of the samples reached the endpoint or failure point after only 7 days exposure. Within these samples, some failed first in black, some in the cyan, some in magenta and some in yellow.

One more sample had reached the endpoint when measured after 21 days exposure to 1 ppm ozone. Two more samples failed at the 35 day measurement.

Three samples, did not fail until the 56 day exposure point. Four more samples were found to have reached the endpoint when measured after 112 days exposure. One sample had not failed at 112 days exposure.

In order to enhance clarity, we have removed the redundant entries from the summary table below. Redundant entries were multiple samples that used the same printer, ink and media. Samples are presented in order of performance, best to worst. The ID numbers used in this summary correspond to the sample ID numbers used in the light fade and high humidity tests.

| ID | Printer | Media | Days of exposure to 1ppm Ozone | | | | |
|---|---|---|---|---|---|---|---|
| | | | 7 | 21 | 35 | 56 | 112 |
| 32 | HP8250 | HP Premium Plus | | | | | |
| 37 | Kodak ES5300 | Kodak Ultra Prem Photo | | | | | |
| 38 | Kodak ES5300 | Kodak Ultra Prem Photo | | | | | |
| 20 | Epson R800 | Epson Premium Glossy Photo | | | | | |
| 36 | Lexmark Z816 | Lexmark Premium Glossy Photo | | | | | |
| 12 | Dell 942 | Dell Premium Photo | | | | | |
| 17 | Epson R800 | Kodak Ultra Prem Photo | | | | | |
| 25 | Epson R2400 | Kodak Ultra Prem Photo | | | | | |
| 21 | Epson 2200 | Kodak Ultra Prem Photo | | | | | |
| 28 | Epson R2400 | Epson Premium Glossy Photo | | | | | |
| 24 | Epson 2200 | Epson Premium Glossy Photo | | | | | |
| 1 | Canon iP6600 | Kodak Ultra Prem Photo | | | | | |
| 4 | Canon iP6600 | Canon Photo Pro | | | | | |
| 5 | Canon i9900 | Kodak Ultra Prem Photo | | | | | |
| 8 | Canon i9900 | Canon Photo Pro | | | | | |
| 9 | Dell 942 | Kodak Ultra Prem Photo | | | | | |
| 13 | Epson R320 | Kodak Ultra Prem Photo | | | | | |
| 16 | Epson R320 | Epson Premium Glossy Photo | | | | | |
| 29 | HP8250 | Kodak Ultra Prem Photo | | | | | |
| 33 | Lexmark Z816 | Kodak Ultra Prem Photo | | | | | |

**Figure 34 - Graphical Summary of Ozone Test Results**

### 7.4.1 Other Comments

It is noticeable that some colors are more affected than others by ozone exposure. This effect is not universal, in that some prints showed most deterioration in cyan and others showed most deterioration in yellow. Any deterioration of one color more than others is likely to result in a more noticeable effect. That is, if all of the colors fade equally by ΔE of 10, some observers might not notice the change, especially if they do not have the original print for reference. If however, only the cyan fades by ΔE of 10, most observers would notice this change.

An example of this is shown when observing the results for prints 20-28. In each case, the cyan patch faded significantly more than the yellow for example. This was also particularly true for the patches with less than 100% density. This effect is likely to be very noticeable in a photographic print that includes these colors in many shades.

It is not universally true that cyan dyes or pigments are most sensitive to ozone exposure. Prints 9, 10, 29 and 30 all showed as much or more fade in yellow as in cyan.

# Appendix A – General Test Image

Target Size = 1.25” x 8.5”

57 Patches, 0.7 mm square with 0.1 mm gap

# Appendix B – Visual Test Image