Issues in Evaluation and Standardization of Light Fading Tests of Ink Jet Materials

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Abstract

The purpose of this study is to reach a better understanding of the complex fading behavior of ink jet prints and to demonstrate the difficulties in providing reliable tests. Test conditions chosen for this research were: high-intensity fluorescent light (framed and unframed samples), airflow, and ozone and nitrogen dioxide to better predict the influence of possible environmental pollutants. Two ink sets, a dye-based and a pigmented one, printed on two different media (a photo glossy and a matte paper), were tested. The samples were read with a spectrophotometer to get an overview of the fading behavior over the whole spectrum. An additional advantage of this approach is to not be limited to the filters used in densitometers, because they are not ideal for the inks used for ink jet printing today. The fading behavior of the various ink concentrations of the samples were monitored and described over time. These data lead to a more detailed description of the fading process than normally published data showing only an endpoint for one specific ink concentration. It is crucial to describe the fading processes as accurately and completely as possible during the time of development of ink jet materials. Advantages and disadvantages of various methods for describing the fading behaviors will be discussed.

Introduction

As digital hard copy output has become an alternative to traditional imaging systems (conventional photography), the question about the permanence of this material is raised. There is no standard for color hard copy materials yet, so the tests have to rely on the precedents established by the photo industry. Due to the fast-growing number of new output technologies, new ink sets and new media, fast test results are required. Because high-intensity/high-concentration, accelerated-aging tests can suffer from reciprocity failure, a reliable long-term life prediction under normal display conditions is difficult to make. Further, color hard copy materials can be negatively effected by many factors like humidity, water and others, some previously unconsidered. Thus, a wider range of test methods than recommended in the ISO 10977 [1] standard is necessary. The most studied and well-known issues are light- and water-fastness; some of the newer ones are humidity- and ozone-fastness.

Test Methods

Samples/Target Specifications

Each target contains ten steps of varying densities from 10 to 100 dot percentage of each of the pure colors (cyan, magenta, yellow) as well as red (containing yellow and magenta only), green (containing yellow and cyan only), blue (containing cyan and magenta only) and black (containing cyan, magenta, yellow and black). The targets were printed on two different desktop printers, both with a six-ink system, on two different papers. Two targets per sample, mounted on different cardboards to avoid significant exposure differences, were exposed for each test.

1. Light Stability Test

The accelerated high-intensity light-fading test was done in a light-fading unit at Image Permanence Institute. Forty-two cool-white fluorescent tubes were used as a light source. To provide a humidity- and temperature-controlled environment and to cool down the tubes, the unit stands in a separate room with an air conditioning system. An air stream of about 1.3 m/s, at 18°C and 55% RH is continuously passed across the tubes and the surface of the test samples to produce a white backing temperature of 20°C ± 2°C and 45% ± 5% RH. The test ran ten weeks (dye samples) and 14 weeks (pigment samples). The measurement of optical density (Status A) as well as the reflectance spectrum of the samples was done once a week with a GretagMacbeth SpectroScan spectrophotometer.

Test Conditions

a. 50 klx light: Samples were exposed to 50 klx fluorescent light and the normal airflow in the light-fading room.
b. Glass filtered: Samples were filtered with window glass and were exposed to 50 klx fluorescent light. There was no airflow and UV light hitting the samples. The spectral energy distribution of the tubes as well as the transmission of the window glass met the standard requirements.
c. Airflow: Samples were exposed only to the normal airflow in the light-fading room and to approximately

150 lx room light (fluorescent light), because the samples were put on the "back" of the unit (Figure 1).

Figure 1. Position of the airflow samples

2. Pollution Test

Accelerated pollution tests using ozone and nitrogen dioxide were added to the light-fading test. As there is neither a standard for ink jet stability tests, nor a standard test method for determining paper deterioration, the testing was done based on an atmospheric pollution aging test developed by IPI. The tests ran 18 days at an ambient temperature of 25°C and a relative humidity of 50% and concentrations of 10 ppm ozone and 10 ppm nitrogen dioxide, respectively. In addition, the two dye-based samples ran four days at an ozone concentration of 1 ppm. Sample readings were done after 1, 2, 3, 4, 7, 14 and 18 days.

Analysis

To analyze all the measured data, the software Microsoft® Excel was used. No calculation of image stability parameters as recommended in the standard was done. The analysis was more focused on looking at the whole behavior of the colorant, i.e., density changes over all step wedges to observe different fading rates in D_{min} (diluted ink) to D_{max} (concentrated ink). For the whole analysis only the raw data were used. No interpolation was done between two step wedges to get $D_{1.0}$ (ISO Standard 10977). Also, no d_{min} (paper density) correction was done, as no significant yellowing occurred. In addition, spectral data were analyzed by plotting them in a graph showing the absorption of the different colorants in various patches over the whole visual spectrum (400-700 nm) at different time periods. This way, it was easy, while fading occurred, to observe changes in the absorption maxima, which can result in color shifts. The spectral readings were used only for visual analysis.

Results[2]

It was not possible to separate each effect that can influence the amount and speed of fading of an ink jet image (i.e., light, humidity, temperature, airflow and pollutants). However, by looking at all the samples aged by the different test conditions, it could be determined, more or less, which fading was caused by VIS light, by UV light, by airflow or by pollutants.

Dye-Based Samples

Density Analysis

The cyan dye was the most stable of the three dyes in VIS light (framed) and the least stable when exposed to unfiltered light, airflow, ozone and NO_2. The magenta dye was the least stable in the VIS and UV light. In terms of airflow, ozone and NO_2, magenta turned out to be fairly stable. The yellow dye was nearly as unstable as the magenta dye in both VIS and UV light. It did not show any significant fading in airflow: only high concentrations of ozone and NO_2 led to density decrease.

Table 1: Summary of the stability of the three dyes on glossy photo paper

Colorant	Light	Filtered	Airflow	Ozone	NO_2
Cyan dye	**very unstable**	**relatively unstable**	**unstable**	**very unstable**	**unstable**
Magenta dye	**very unstable**	**unstable**	**relatively stable**	**unstable**	**relatively stable**
Yellow dye	**very unstable**	**unstable**	**stable**	**relatively stable**	**unstable**

Key of evaluation:
Very stable: no fading, fading rate below 4%
Stable: almost no fading, fading rate below 10%
Relatively stable: slow fading rate, max. 20% after eight weeks
Unstable: approx. 10% fading rate after the first week of exposure, max. up to 40-50%
Very unstable: over 15% fading rate after the first week of exposure, max. up to 60-70%

Catalytic Fading

Only the cyan dye showed some catalytic fading under the glass-filtered and the airflow conditions in all patches. The magenta dye showed some catalytic fading as well, mainly in the blue patches in the presence of the cyan dye.

Ink/Media Interaction

The dyes printed on glossy photo paper and on matte paper show similar trends in the behavior and tendency to fade. Samples printed on matte paper showed an overall lower fading rate over time. This is due to the surface structure which allows the ink to penetrate more deeply into the medium and so stabilizes the dye to a certain degree. The influence of the media on the stability of the dye could be seen best with the cyan dye. When printed on glossy photo paper, which is a so-called microporous paper, the dye was very unstable against airflow. This can be explained by the microcapillaries which keep the ink near the surface; thus, the dyes are less protected against environmental influences. There does not necessarily have to be a pollutant like ozone present to decompose the cyan dye. Samples exposed to airflow (150 lx) in the light-fading room showed significantly more fading after 35 days (real time) than the samples exposed for one day to 1 ppm O_3, which equals forty days at an average of 0.025 ppm O_3 (Figure 2).

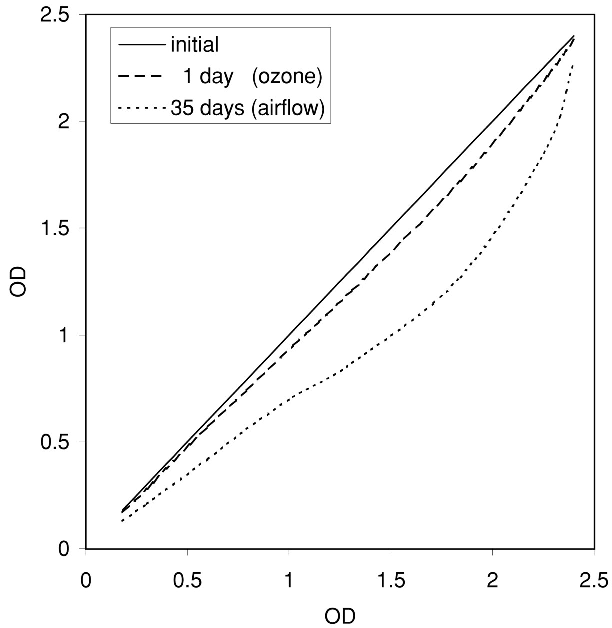

Figure 2. Cyan dye printed on glossy photo paper and exposed to airflow of 1ppm O_3. The x-axis show the initial optical density (OD) and the y-axis the OD of the faded patches.

Table 2. Summary of the color shifts observed in each color patch. The first row represents the color shifts that occurred on glossy photo paper and the second row represents those that occurred on matte paper.

Colorant	Light	Filtered	Airflow	Ozone	NO_2
Cyan patch	**yellowish** **yellowish**		**yellowish**	**yellowish**	**yellowish** **greenish**
Magenta patch					
Yellow patch	**muddy** **muddy**	**muddy** **muddy**			**muddy** **muddy**
Red patch	**yellowish** **yellowish**	**yellowish** **yellowish**	**yellowish** **yellowish**	**yellowish** **yellowish**	**magenta** **magenta**
Green patch	**muddy** **bluish**	**bluish** **bluish**	**yellowish** **bluish**	**yellowish** **bluish**	**yellowish** **bluish**
Blue patch	**reddish** **greenish**	**greenish** **greenish**	**reddish** **greenish**	**reddish** **greenish**	**reddish** **reddish**
Neutral patch	**reddish** **greenish**	**greenish** **greenish**	**yellowish** **yellowish**	**yellowish** **yellowish**	**magenta** **magenta**

The surface structure had less influence on the samples positioned behind glass, because the airflow was cut off.

Spectrum Analysis

Spectrophotometry makes it possible to get an overview of the fading behavior over the whole spectrum. Further, it eliminates the problem of being limited to the filters used in densitometers, which are optimized for photographic materials and do not match the absorption maxima of dyes or pigments.

The fading behavior of the single dyes could be recognized in the mixed patches as well. Further, different density patches of one color showed different color shifts. The greatest color shift was observed in the neutral patches printed on glossy photo paper, where the high densities turned greenish while the low densities turned slightly red. This so-called "cross-curves" effect makes it necessary to look at more than one density patch to make a reliable prediction about how an image might look after fading.

Pigment-Based Samples

Density Analysis

In general, the pigmented ink was much more stable than the dye ink. However, when fading occurred, the pigments showed the same fading behavior as the dyes. Cyan, for example, turned out to be unstable when exposed to VIS light, airflow and ozone both as a dye and as a pigment. The magenta dye faded most when exposed to light, and so did the magenta pigment. Both the yellow dye and pigment were fairly stable when exposed to airflow and pollutants. The highest rate of fading was observed in the diluted cyan pigment when exposed to 50 klx light. It was the only one to reach 30% density loss.

Table 3. Summary of the stability of the three pigments on glossy photo paper

Colorant	**Light**	**Filtered**	**Airflow**	**Ozone**	**NO_2**
Cyan pigment	unstable	very stable	relatively stable	relatively stable	stable
Magenta pigment	relatively stable	stable	stable	relatively stable	stable
Yellow pigment	relatively stable	very stable	very stable	very stable	stable

Key of evaluation:
Very stable: no fading, fading rate below 4%
Stable: almost no fading, fading rate below 10%
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Unstable: approx. 10% fading rate after the first week of exposure, max. up to 40-50%
Very unstable: over 15% fading rate after the first week of exposure, max. up to 60-70%

Ink/Media Interaction

Since there was little fading, there were few ink/media interactions to observe. But all pigments printed on matte paper showed an overall better stability than those printed on glossy photo paper.

Spectrum Analysis

Only small color shifts were observed, and they occurred only when printed on glossy photo paper. If the patches did show changes, they were always in the same direction as those of the dye samples.

Table 4. Summary of the color shifts observed in each color patch on glossy photo paper.

Colorant	Light	Filtered	Airflow	Ozone	NO_2
Cyan patch	**yellowish**				
Magenta patch					
Yellow patch					
Red patch	**yellowish**			**yellowish**	
Green patch	**yellowish**			**yellowish**	
Blue patch					
Neutral patch	**reddish**			**reddish**	

Conclusion

To provide reliable tests, the operating conditions have to be set and monitored closely. This complicates the tests and makes them rather complex. In some cases it is not possible to measure and control every influencing effect, which will make it difficult to interpret the test results. In addition, measurement procedures have to be specified and closely followed.

The test targets should include steps of varying densities, because of the different fading occurring in the lower and higher density patches. This effect makes it necessary to look at more than one patch. To get even more information about the fading behavior, a spectrophotometer instead of a densitometer should be used giving an overview over the whole spectrum.

All those issues have to be kept in mind when conducting fading test of ink jet images. In a research environment where inks and media are being optimized, the tests have to be even more controlled and the analysis needs to be even more complex. For consumer testing the analysis, or at least the results, should be less complicated, because the consumer just wants to know how long the ink jet print is going to last. However, it has to be emphasized, that the consumer should get a full disclosure of any fading problems.

Without controlled and standardized test methods, test results are not reliable. To compare various inks, media and ink/media combinations all over the world, a controlled, standardized and reproducible test is necessary. However, taking care of all these issues delays the progress of the new standard for methods for measuring image stability for color hardcopy.

References

1. ISO Standard 10977: Photography—Processed photographic color film and paper prints—Methods for measuring image stability, (1993)
2. Barbara Vogt, thesis at the department of Image Engineering, University of Applied Science, Cologne: Stability Issues and Test Methods for Ink Jet Materials (2001), online: www.rit.edu/ipi

Biography

Barbara Vogt joined the Image Permanence Institute, RIT in Rochester, NY as a research assistant for one year. Her work there was focused on the stability issues and test methods of ink jet materials. Since 1995 she has studied image engineering at the University of Applied Science in Cologne, Germany. From 1988 until 1995 she worked as a chemical technician in a pharmaceutical enterprise.