

Title

Image Stability Behaviors of KODAK PROFESSIONAL Inkjet Photo Paper

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Abstract

The long-term stability of inkjet photographic prints is known to be sensitive to a variety of factors. The chemical composition of the inks (pigments vs. dyes) and media (porous vs. swellable), as well as the ambient environmental conditions (light, heat, humidity, air quality) under which the prints are stored and/or displayed, are known to affect image stability. The KODAK PROFESSIONAL Inkjet Photo Paper not only maintains broad compatibility with all popular desktop inkjet printers, but also offers excellent image stability under typical home display and storage conditions. When printed with current state-of-the-art pigmented inks, prints made on KODAK PROFESSIONAL Inkjet Photo Paper are projected to last in excess of 100 years, even when displayed without additional protection, such as behind glass. In this paper, we will discuss the details behind the image stability testing and results that are key to the inkjet paper.

Introduction

When purchasing high quality inkjet paper for printing photographic images, photographers face two choices: swellable polymer-based coatings or porous inorganic particle-based coatings. This decision comes with inherent trade-offs. While porous coatings dry quickly after printing and their moisture and humidity resistance is generally good, resistance to environmental pollutants such as ozone is quite poor, especially if printed with dye-based inks.¹ Swellable coatings offer improved lightfastness and stability to pollutants, but tend to be sensitive to high humidity from both a dry time and image stability perspective.²

Clearly, it is desirable to have a photo-quality inkjet paper that can stand up to all of these environmental factors, even under the most demanding consumer application: unprotected display, such as on the refrigerator, on the bulletin board, or in an open frame.³ KODAK PROFESSIONAL Inkjet Photo Paper allows the professional photographer to produce a professional inkjet image comparable to a silver halide print. When used together with pigmented ink technology, KODAK PROFESSIONAL Inkjet Photo Paper can provide professional quality photos with excellent resistance to those same environmental factors.

Universal Compatibility

KODAK PROFESSIONAL Inkjet Photo Paper has been, and continues to be, tested on numerous photo-quality inkjet printers. Each pack of paper comes with an instruction sheet that shows photographers how to optimize their specific printer driver settings to create high quality, pleasing prints. The photographer is also directed to the web site for custom ICC profiles that can be downloaded and used to make professional photographic quality prints. The result is excellent color and image quality with KODAK PROFESSIONAL Inkjet Photo Paper on the most popular professional printers.

Image Stability: A Question of Balance

To adequately characterize the expected print life of a photographic print, all known environmental factors must be considered. For example, inkjet prints are known to be affected by:

- Light
- Heat
- High humidity
- Ozone

Unprotected display is the most demanding condition because a print is simultaneously exposed to all four factors. Recent print life claims made by several manufacturers of inkjet media have been limited to only light fade, and this estimate is only accurate if the print is protected behind glass. In order to estimate the print life of KODAK PROFESSIONAL Inkjet Photo Paper, we assume unprotected home display conditions and test against all four factors.

There are no current standard test methods that address the estimation of print life for digital photographic output across the relevant environmental factors listed above. However, the current ANSI/ISO standard⁴ that has been used for traditional chromogenic silver halide materials does offer some guidance with respect to accelerated testing for the effects of light and heat.

Overall print life is assumed to be only as good as the “weakest link”, i.e., overall print life will be limited by the factor that produces the lowest estimate. Thus, a print that might be projected to last 100 years based on light fade, but only 6 months with respect to ozone fade, would result in a print life estimate of 6 months.

The End-User Environment

Before any estimate of print life can be made, one must first determine the typical environment that represents the intended use of the product. For KODAK PROFESSIONAL Inkjet Photo Paper, the intended use environment is the typical consumer of professional images, (images such as family portraits and wedding pictures). These images are both displayed and stored in albums. Published studies by Anderson and coworkers in the 1980s suggest that the typical home environment is represented by a temperature of about 20°C (68°F), a relative humidity (RH) of about 50%, and a light intensity in the range of 100-150 lux for 12 hours during the day.^{5,6} We have recently completed an even broader study of 32 homes in 4 cities around the world, and the results are essentially the same: 20°C \pm 3.5° (\pm 1 σ), 51% \pm 11% RH (\pm 1 σ), and \leq 137 lux per 12 hour daytime cycle (90th percentile).⁷ Therefore, for the purposes of accelerated print life testing, we have defined the typical home display environment as 23°C, 50% RH, and 120 lux per 12 hour daytime cycle (1440 lux-hr/day). This is the same assumption used for traditional silver halide prints as well as thermal dye transfer prints.⁸

For imaging materials that are sensitive to ozone, one must also define the typical ozone levels that might be encountered in the home display environment. A recent study by Epson, in which the fade of inkjet print samples placed in homes was monitored for almost a year and correlated to controlled laboratory ozone-faded samples, concludes that long-term ozone levels are close to 5 ppb.¹⁹ Our own studies,⁷ and those of others,¹⁰ are consistent with this estimate. Therefore, for the purpose of estimating the long-term effects of ozone on KODAK PROFESSIONAL Inkjet Photo Paper, we assume an average daily exposure of 5 ppb, at the temperature and humidity levels listed above.

End-Points

Another key assumption for the estimation of print life is the definition of how much image quality loss is acceptable before a print is deemed “end of life”, in other words, ready to be discarded. For environmental factors such as light and heat, which are known to primarily cause prints to fade, loss of optical density (as measured by Status A densitometry) has long been used to measure loss of image quality. The current ANSI/ISO standard⁴ that has been used for estimating print life for traditional chromogenic silver halide materials⁸ contains “illustrative end-points” based on the loss of density measured from an initial density of 1.0, corrected for D_{\min} . There are also end-points based on background staining or yellowing leading to an increase in D_{\min} . Refer to Table 1 for a list of the ANSI/ISO illustrative end-points.

Recent psychophysical studies have shown that these end-points are in fact quite conservative with respect to the end-users’ expectations.^{11,12} While we consider them to be quite conservative we will use these same end-points to estimate the print life of KODAK PROFESSIONAL Inkjet Photo Paper with respect to light and heat. Because the primary effect of ozone on prints is also loss of density, it makes sense to use the same end-points for this estimate as well.

As opposed to simple dye fade, humidity is known to have a more complicated effect on image quality degradation.² Density gain, hue shift, and loss of sharpness are all common observations for prints that are sensitive to humidity. In contrast to loss of density, there are no existing guidelines for what constitutes an end-point with respect to these types of image quality degradation. The good news is that at 20-25°C and 50% RH, as represented by the typical home environment as defined above, the effect of humidity on image quality of most inkjet prints is negligible.^{2, 13} In other words, at 20-25°C and 50% RH, humidity is not considered to be a limiting factor with respect to print life for most inkjet media, including KODAK PROFESSIONAL Inkjet Photo Paper.

Table 1. ANSI/ISO Illustrative End-points

	Starting Color	End-Point (% loss from 1.0 initial density)
Cyan Fade	Cyan	30% loss
Magenta Fade	Magenta	30% loss
Yellow Fade	Yellow	30% loss
Black Fade	K	30% loss
Cyan Fade	CMY	30% loss
Magenta Fade	CMY	30% loss
Yellow Fade	CMY	30% loss
Red-Green	CMY	15% loss
Red-Blue Color	CMY	15% loss
Green-Blue	CMY	15% loss
Cyan Stain	Dmin	.10 density increase
Magenta Stain	Dmin	.10 density increase
Yellow Stain	Dmin	.10 density increase

For systems that are sensitive to humidity, noticeable changes are not observed until the RH at room temperature rises above about 70%.^{2,13} Although the typical home display environment is closer to 50% RH, the range of humidities can sometimes exceed 70%.⁷ Since no metrics and end-points are currently available for humidity-induced image quality degradation, we assessed end-user acceptability of image quality after treatment at high humidity by two methods: (a) Status A density change and (b) a psychophysical study.

For the densitometric method, we used the same relative end-points as used for fade. In other words, a 30% gain in density would be considered an end-point in the case of humidity, just as a 30% loss of density would be in the case of light, ozone, or thermal fade. For the psychophysical analysis we looked at relative quality degradation against samples of known levels of multivariate image quality.

Results

The tests results presented in the following sections describe the effect of each of the four environmental factors on images produced using KODAK PROFESSIONAL Inkjet Photo Paper. For each environmental factor, the test method used is described in detail.

Prints made with the EPSON STYLUS Photo 2200 printer and EPSON ULTRACHROME pigmented inks are used as a primary representation of the printing system used by many professional and advanced amateur photographers to produce photographic-quality output. The EPSON STYLUS Photo 2200 printer utilizes a set of seven pigmented inks and the user has the option to select either a 'Matte Black' or 'Photo Black' ink depending upon the surface gloss characteristic of the paper used for printing a particular image. For these tests using KODAK PROFESSIONAL Inkjet Photo Paper, the 'Photo Black' ink was used. A digital imaging workflow (including manufacturer's printer driver settings) representing the typical workflow of professional and advanced amateur photographers was used to produce the prints.

It is recognized that a range of printers are used commonly by professional and advanced amateur photographers for producing photographic-quality output. The range of printers includes Epson printer models with different ink sets (e.g. EPSON STYLUS Pro 4000, EPSON STYLUS Pro 7600, EPSON STYLUS Photo R800, and EPSON STYLUS Photo R1800 printers using pigmented inks). Image-stability results from these EPSON printers will be similar to the results observed using the EPSON STYLUS Photo 2200 printer with the specified set of pigmented inks.

Image-stability results for photo-quality Canon printers using dye-based ink sets (represented by the Canon i950 photo printer) are also reported.

Light Fade

For accelerated light fade, polycarbonate-filtered fluorescent lighting at various intensities was used as the accelerating condition.¹⁴ The temperature and humidity were maintained as close as possible to 23°C and 50% RH, and ozone was kept below detection.¹⁵ This is the same condition commonly used for traditional silver halide testing⁸ and is adapted from the current ANSI/ISO standard.⁴

For this study, we are testing at 80 klux at the Kodak's Image Stability Technical Center. The use of both very high intensity (50-80 klux) and moderately high intensity (5-7 klux) light is necessary to assess any significant deviations from reciprocity. At this time, only the high intensity condition has reached endpoints; these are the results that are reported below. We will continue to monitor the lower intensity tests to make sure there are no surprises. However, we fully expect that for many of the current pigmented ink sets we will not see endpoints reached for close to two full years of treatment at the 5-7 klux level.

Measurements of density loss are made as a function of exposure until at least one end-point is reached and the end-point is used as a basis for calculating the projected light-fade print life. Table 2 summarizes our current light-fade results for KODAK PROFESSIONAL Inkjet Photo Paper in combination with the EPSON ULTRACHROME ink sets for the EPSON STYLUS R800 and 2200 printers and CANON i950 ink/prINTER system.

Table 2. Light-Fade Test Results for KODAK PROFESSIONAL Inkjet Photo Paper

Printer	Current Cumulative Exposure (Mlux-hr)	End-point Reached?	Light Fade Print-life Estimate	Ink technology	Comments
EPSON 2200	54	No	>100yr	pigment	linear extrapolation of magenta (<5% density loss at this time)
EPSON R800	54	No	>100 yr	pigment	linear extrapolation of yellow in neutral (<4% density loss at this time)
CANON i950	54	Yes	37	dye	linear extrapolation of magenta in neutral $R^2=0.95$

Ozone Fade

Ozone is the Achilles heel of prints made on porous media using dye-based inks. However, when KODAK PROFESSIONAL Inkjet Photo Paper is used in combination with pigmented inks, excellent ozone stability is achieved. Even with dye-based inks, prints that are stored or displayed behind glass should provide years of customer satisfaction. When porous media is used with dye-based inks, noticeable fade occurs with just a few weeks' exposure to ambient air containing just a few ppb of ozone.⁹ However, more stable pigmented inks printed on KODAK PROFESSIONAL Inkjet Photo Paper require the use of much higher concentrations of ozone. For accelerated ozone fade, we have developed a methodology very similar to that used for light fade.¹ As with accelerated light fade, we assume a reciprocal relationship between ozone concentration and time of exposure. The test chamber and methods have all been documented in detail elsewhere.^{16, 17}

Table 3 summarizes our current ozone fade test results for KODAK PROFESSIONAL Inkjet Photo Paper in combination with the EPSON ULTRACHROME ink sets with the EPSON STYLUS Photo R800 and 2200 printers. As with light fade, measurements of density loss are made as a function of treatment until at least one end-point is reached. The projected ozone fade print life is based on the first end-point reached.

Table 3. Ozone Fade test Results for KODAK PROFESSIONAL Inkjet Photo Paper

Printer	Current Cumulative Exposure (ppm-hr)	End-point Reached?	Ozone Fade Print-life Estimate	Comments
EPSON R800	4272	Yes	131 yr	cyan density loss
EPSON 2200	4272	Yes	103 yr	linear extrapolation of cyan (28% density loss at this time)

High-Humidity

For accelerated humidity testing, we test at the following conditions at the Kodak's Image Stability Technical Center.

38°C/80% RH, ozone free, dark, 28 days

30°C/70% RH, ozone free, dark 56 days

In terms of absolute humidity, both of these conditions are equivalent to $\geq 100\%$ RH at 23°C (72°F). For dye-based inks on most inkjet media, the kinetics of humidity-induced change are such that nearly all of the measurable change occurs within the first 7 to 14 days at 38°C/80% RH.² At 30°C/70% RH, the rate of change is slower overall, but the results eventually plateau near the same levels observed at 38°C/80% RH. After 14 days at 38°C/80% RH condition, KODAK PROFESSIONAL Inkjet Photo Paper in combination with the CANON i950 ink set exhibits minimal density gain, hue shift and/or loss of sharpness. The total change, from either test condition, does not result in any end-points being reached, nor does it cause the image quality to degrade to an unacceptable level.

Table 4 summarizes our current high-humidity test results for KODAK PROFESSIONAL Inkjet Photo paper in combination with the ULTRACHROME ink sets for the EPSON STYLUS R800 and 2200 printers, as well as the CANON i950 ink/printer system.

Table 4. High-Humidity Test Results for KODAK PROFESSIONAL Inkjet Photo Paper with EPSON ULTRACHROME Inks and CANON ink/printer systems.

Printer	38C / 80%RH/28 days	30C / 70%RH / 56 days	End-point Reached?	Ink technology	Humidity Fade Print-life Estimate
EPSON 2200	tested	tested	No	pigment	>100yr
EPSON R800	tested	tested	No	pigment	>100 yr
CANON i950	tested	tested	No	dye	>100 yr

Thermal Fade and Yellowing

For estimating the long-term effects of thermal dye stability, the Arrhenius method (as described in the current ANSI/ISO standard⁴) is used. The free-hanging condition is more representative of an unprotected print on display. Because of the known interactions of heat and humidity for inkjet prints, the constant dew point of 13.9 °C is maintained in order to measure the rates of fade at multiple temperatures above ambient¹³ (this is equivalent to 50% RH at 25°C).

As with the light fade and high humidity testing, care is taken to exclude ozone from the test chambers used for the Arrhenius study.

Because the rate of change is very slow at the lower temperatures, this test can take many months or even years to complete. Currently, we have not seen enough fade at even the higher temperatures for KODAK PROFESSIONAL Inkjet Photo Paper (in combination with multiple ink sets) to be able to establish a meaningful rate of fade. Likewise, we have not seen yellowing of any significance. KODAK PROFESSIONAL Inkjet Photo Paper is comparable with another KODAK inkjet paper, KODAK Ultima Picture Paper, for thermal stability. Long-term testing is much further along with KODAK Ultima Picture Paper. The lack of fade and yellowing with KODAK PROFESSIONAL Inkjet Photo Paper is consistent with our previous Arrhenius results on KODAK Ultima Picture Paper, and allows us to conclude that thermal fade and thermal yellowing will not be limiting factors for an unprotected print on display. We will update these results and conclusions as more data become available.

Summary

In summary, KODAK PROFESSIONAL Inkjet Photo Paper, in combination with high-quality pigmented inks, is estimated to last for over 100 years when displayed unprotected in a typical home environment. Total print life appears to be limited by ozone fade, followed by light fade. Humidity and thermal effects are less significant. We will update these results periodically as new data become available.

Notes and References

1. M. Oakland, D. E. Bugner, R. Levesque, and R. Van Hanehem, *Proc. NIP 17*, 175-178 (2001).
2. P. Hill, K. Sutor, and P. Artz, *Proc. NIP 16*, pp. 70-73 (2000).
3. D. Bugner and C. Romano, "Printing Memories to Last a Lifetime: Understanding Image Stability of Inkjet Prints," *Recharger Magazine*, September 2001.
4. ANSI IT-9.9 (1996) (soon to be ISO 18909).
5. S. Anderson and G. Larson, *J. Imaging Technol.*, 13, pp. 49-54 (1987).
6. S. Anderson and R. Anderson, *ibid.*, 17 (3), pp. 127-131 (1991).
7. D. E. Bugner, J. LaBarca, D. Kopperl, J. Phillips, D. Skye, I. Baker, C. Cunningham, P. Miller, and T. Kaltenbach, *Proc. IS&T's 13th Int. Symp. on Photofinishing*, in press, (2004).
8. J. LaBarca and S. F. O'Dell, *Proc. of IS&T's 12th Int. Symp. on Photofinishing*, pp. 38-47 (2002).
9. K. Kitamura, Y. Oki, H. Kanada, and H. Hayashi, *Proc. NIP 19*, pp. 415-419 (2003).
10. M. Thornberry and S. Looman, *ibid.*, pp. 426-430 (2003).
11. D. Oldfield, G. Pino, R. Segur, J. P. Twist, and S. O'Dell, *ibid.*, p. 396 (2003).
12. H. Ishizuka, Y. Seoka, Y. Shibihara, and E. Sakai, *ibid.*, pp. 411-414 (2003).
13. M. Oakland, D. E. Bugner, R. Levesque, and P. Artz, *Proc. NIP 17*, pp. 167-170 (2001).
14. D. E. Bugner and C. Suminski, *Proc. NIP 16*, pp. 90-94 (2000).
15. D. E. Bugner, D. Kopperl, and P. Artz, *Proc. of IS&T's 12th Int. Symp. on Photofinishing*, pp. 54-57 (2002).
16. D. E. Bugner, R. Van Hanehem, P. Artz, and D. Zaccour, *Proc. NIP 19*, pp. 397-401 (2003).
17. D. E. Bugner, R. Van Hanehem, M. Oakland, P. Artz, D. Zaccour, and R. Levesque, paper to be submitted to *J. Imaging Sci. Tech.*