How Long Will They Last? An Overview of the Light-Fading Stability of Inkjet Prints And Traditional Color Photographs

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Abstract

Inkjet printing of photographs has become the most common form of output from digital camera files and in 2002 inkjet printing will start to expand from the desktop to higher volume minilab and stand-alone kiosk applications. At the same time, the proliferation of digital silver-halide printers in minilabs, and increasingly in centralized wholesale labs, has brought traditional process RA-4 silver-halide photographic papers firmly into the digital output world. This paper gives an overview of the various factors affecting the light fading stability of both types of color prints. The similarities and differences between inkjet prints, made with both dye-based and pigmented inks, and traditional chromogenic color prints are discussed in the context of image stability, and certain improvements in test methods are proposed.

Introduction

With the rapid proliferation of affordable, high-quality digital cameras, scanners, and digitized image files made from color negative and transparency originals, there has been tremendous growth in the use of inkjet printers, digital minilabs, and other digital output devices for printing color photographs. As these new technologies continue to rapidly advance into mainstream markets, many questions have been asked about how the permanence of inkjet and other types of digital prints compares with that of traditional silver halide color prints.

For the majority of consumer digital camera users, inkjet printing has become the primary – and often the only – method of making prints from their digital image files. For these people, inkjet-printed photographs are either displayed framed under glass (or not framed and displayed freely exposed to the ambient air) in their homes and offices, placed in albums, posted on refrigerator doors, or otherwise used in the same ways that photographs have always been used. For most people, inkjet prints *are* photographs and they think about them in much the same way they have always thought about color photographs – and they also have the very same expectations about image permanence.

Because high-quality photographs printed with desktop inkjet printers have come into significant use only since 1998, people have no long-term experience with these new products of a very different and rapidly evolving technology. Consumers are confronted with a bewildering choice of inkjet printers (virtually all of which are now advertised as being "photo quality") and countless types of inkjet photo papers. "How long will these inkjet prints last and how do they compare with traditional color prints?" is a frequently heard question.

The same question is also increasingly being asked by professional photographers, photo labs, service bureaus, commercial galleries, fine art publishers, interior decorators, and countless other producers and users of photographs. In addition, it is critically important for museum curators and archivists to know the answers to this question.

In professional portrait and wedding photography markets, a major growth area for high-quality inkjet printing, good print permanence is essential. Good humidity-fastness behavior and dark storage stability under the wide range of temperature and humidity conditions found in homes throughout the seasons in diverse geographic locations is also required.

A high level of resistance to the effects of air pollutants, or "gas-fading" as it has recently come to be known, is another essential attribute. Taking into account the all-important "intrinsic light stability" of a particular ink/media combination, the many display, storage, and use factors both separately and together influence the useful life of displayed inkjet prints and traditional color photographs.

The Permanence of Displayed Prints

Illumination intensity and spectral distribution, method of framing (or display without framing under glass), temperature, and relative humidity can all influence rates of fading, degree and direction of color balance changes, and yellowish stain formation that occur over time from exposure to light when prints are displayed. Table 1 gives the "predicted years of display before noticeable fading occurs" for a variety of inkjet prints made with dye-based and pigmented inks as well

Table 1. Predicted "Years of Display" Before Noticeable Fading Occurs with Color Prints

Desktop Inkjet Printer and Inks	Print Paper and Type of Coating	Years of display before noticeable fading occurs[1] (prints framed under glass)
Printer: Canon S800 Photo Printer **Ink:** Canon BCI-6 (6-ink, dye-based)	Canon Photo Paper Pro PR-101 (microporous coating)	27 years[2]
	Canon Glossy Photo Paper GP-301 (microporous coating)	6 years[2]
Printer: Epson Stylus Photo 890, 1280, 870, and 1270 **Ink:** Epson inks (6-ink, dye-based)	Epson ColorLife Photo Paper (swellable polymer coating)	26 years
	Epson Matte Paper – Heavyweight (matte coated paper)	25 years
	Epson Premium Glossy Photo Paper (v2001) (microporous coating)	9 years[2]
	Epson Photo Paper (microporous coating)	6 years[2]
Printer: Epson Stylus Photo 2000P **Ink:** Epson "Archival" (6-ink, pigmented)	Epson Premium Luster Photo Paper (microporous coating)	More than 100 years
	Epson Premium Semi-Gloss Photo Paper (microporous coating)	More than 100 years
	Epson Enhanced [Archival] Matte Paper (matte coated paper)	More than 100 years
Printer: Hewlett-Packard PhotoSmart P-1000, 1215, DeskJet 970 series **Ink:** HP #78 (4-ink, dye-based)	HP Colorfast Photo Paper (swellable polymer coating)	19 years
	HP Premium Plus Photo Paper (swellable polymer coating)	5 years[3]
	HP Premium Photo Paper (swellable polymer coating)	3 years[3]
Printer: Kodak Personal Picture Maker PPM200 (mfg. by Lexmark) **Ink:** Kodak "Photo" (6-ink, dye-based)	Kodak Ultima Picture Paper, High Gloss (swellable polymer coating)	24 years[3]
	Kodak Premium Inkjet Paper, Matte (matte coated paper)	6 years[3]
	Kodak Picture Paper, Soft Gloss (microporous coating)	3 years[2, 3]
Printer: Lexmark Z52 Color Jetprinter **Ink:** Lexmark "Photo" (6-ink, dye-based)	Kodak Premium Picture Paper, High Gloss (swellable polymer coating)	Less than 1 year
Traditional Chromogenic Color Prints	Fujicolor Crystal Archive Paper (multilayer gelatin-coated RC photo paper)	60 years[4]
	Kodak Ektacolor Edge 8 Paper (multilayer gelatin-coated RC photo paper)	22 years[4]

1) Predictions based on accelerated light stability tests conducted at 35 klux with glass-filtered cool white fluorescent illumination at 24°C and 60% RH. Data were extrapolated to display conditions of 450 lux for 12 hours per day using WIR Visually-Weighted Endpoint Criteria Set v2.0 (reciprocity failures are assumed to be zero). 2) Field experience has shown that, as a class of media, microporous papers used with dye-based inks can be very vulnerable to "gas fading" when displayed unframed and/or stored exposed to the open atmosphere where even very low levels of certain air pollutants are present; to a greater or lesser degree, these papers have a pronounced sensitivity to pollutants such as ozone and, in some locations, displayed unframed prints have suffered from extremely rapid image deterioration. 3) These ink/media combinations have poor humidity-fastness and, when stored or displayed in commonly encountered conditions of high relative humidity, over time the prints may suffer from one or more of the following: color balance changes, density changes, lateral ink bleeding, "bronzing" in high density areas, and sticking and ink transfer. 4) Display-life predictions integrated with the manufacturer's Arrhenius dark stability data. Note: An earlier version of this table was included in an article by Anush Yegyazarian entitled, "Fight Photo Fade-Out," *PC World*, July 2001, pp. 48–51.

Table 2. WIR Visually-Weighted Endpoint Criteria Set v3.0 for Color Image Print Stability Tests

Ref. No.	Allowed Percentage of Change in Initial Status A Densities of 0.6 and 1.0[1]	Image Change Parameter
1	25%	Loss of cyan (red density) in neutral patches
2	20%	Loss of magenta (green density) in neutral patches
3	35%	Loss of yellow (blue density) in neutral patches
4	30%	Loss of cyan (red density) in pure color cyan patches
5	25%	Loss of magenta (green density) in pure color magenta patches
6	35%	Loss of yellow (blue density) in pure color yellow patches
7	12%	Cyan minus magenta (R – G) color imbalance in neutral patches
8	15%	Magenta minus cyan (G – R) color imbalance in neutral patches
9	18%	Cyan minus yellow (R – B) color imbalance in neutral patches
10	18%	Yellow minus cyan (B – R) color imbalance in neutral patches
11	18%	Magenta minus yellow (G – B) color imbalance in neutral patches
12	18%	Yellow minus magenta (B – G) color imbalance in neutral patches
Change Limits in Minimum-Density Areas (Paper White) Expressed in Density Units		
13	.06	Change [increase] in red or green density
14	.15	Change [increase] in blue density
15	.05	Color imbalance between red and green densities
16	.10	Color imbalance between red and blue densities
17	.10	Color imbalance between green and blue densities

[1]Initial (starting) densities are absolute measurements (not measured "above d-min"). A weighted criteria set for fading, color balance shifts, and d-min stain was first developed by H. Wilhelm in 1978–83 and was slightly modified in 1990, 1992, and 1996. Version 3.0 above was implemented on August 25, 2001 and for the first time included 0.6 starting densities for pure color cyan, magenta, and yellow in addition to the 1.0 starting densities for the pure color primaries that had been employed in earlier versions of the weighted criteria set. From the outset, the neutral scale parameters have always included both 0.6 and 1.0 starting densities.

as two current types of chromogenic color papers.[1] These predictions are based on prints framed under glass and illuminated at 450 lux for 12 hours per day. Dye fading and color balance changes that constitute "noticeable fading" are specified in the visually-weighted criteria set in Table 2. Visually-weighted endpoint criteria sets were developed by H. Wilhelm beginning in 1978 and are based on psychrometric evaluations of groups of incrementally-faded Kodak Ektacolor prints of representative portraits and wedding pictures photographed by professional photographers.[2] Version 3.0 listed here is being employed by Wilhelm Imaging Research, Inc. for current image permanence evaluations. For the products listed in Table 1, an earlier version of the weighted endpoint criteria set was used which employed endpoints for pure color cyan, magenta, and yellow only at 1.0 starting density.

The addition of endpoints for pure color primaries at 0.6 starting densities would reduce the predicted years of display rating for some, but not all, of these products. Future publi-

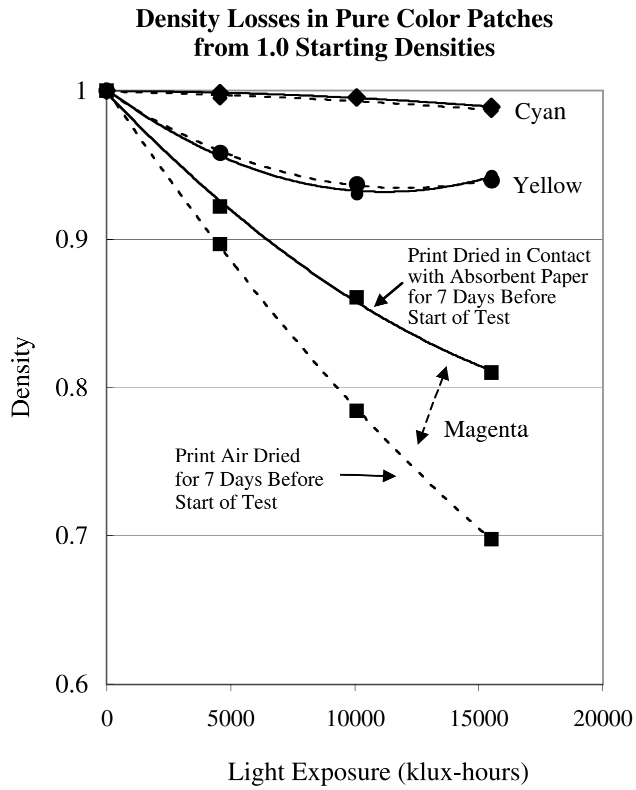

Figure 1. Influence of drying method on the light stability of inkjet prints made with Epson Premium Glossy Photo Paper (a microporous-type media) and an Epson Stylus Photo 890 printer using standard 6-ink Epson dye-based inks.

cation of data for these materials will reflect these changes where they occur. Investigations conducted at Wilhelm Imaging Research, Inc. have shown that with dye-based inkjet prints, the drying method and the period between the time of printing and the start of an accelerated light fading test frequently will have a major impact on measured light stability. Figures 1–3 show the influence of two "drying" methods on the stability of prints made with microporous Epson Premium Glossy Photo Paper (v.2001) and an Epson 890 printer.

Figure 4 is for a swellable-polymer glossy photo paper printed with a dye-based 4-ink printer. In terms of evaporation of water from freshly made prints, it is believed that prints become "dry," or in moisture-equilibrium with the surrounding atmosphere, within a maximum of approximately eight hours after printing. (Because microporous papers instantly absorb water-containing inks upon contact with the print surface, they appear to be fully dry immediately upon emerging from the printer. However, the absorbed water will slowly diffuse from the microporous structure and evaporate during the hours following printing until equilibrium with the surrounding air is reached.)

In normal display and use, prints are naturally "aged" for periods of months and years and accelerated test procedures should take this into account if test results are to be meaningful. These investigations of "drying" conditions suggests that the usual industry practice of air-drying prints for a few days prior to the start of light stability tests will seriously underestimate the light stability of many ink/media combinations. For the past several years, this author has provided

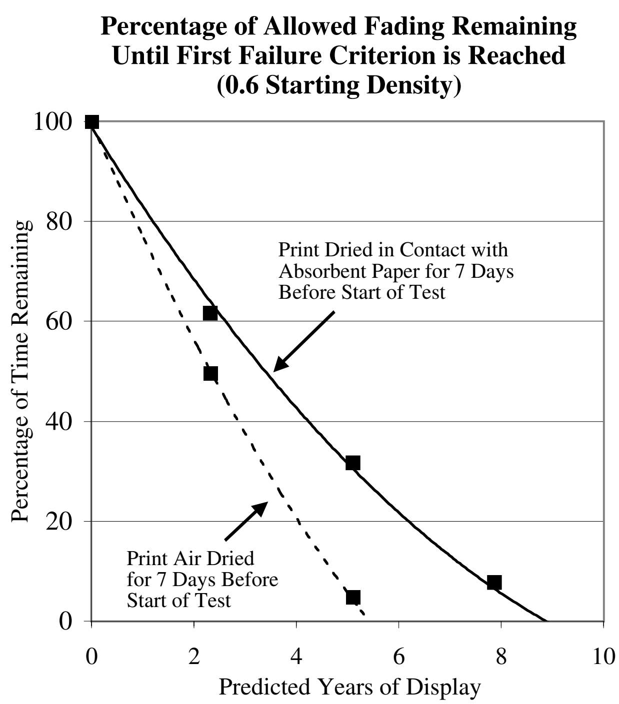

Figure 2. Effects of print drying method on "predicted years of display" for Epson PGPP/890 at 0.6 starting density (magenta).

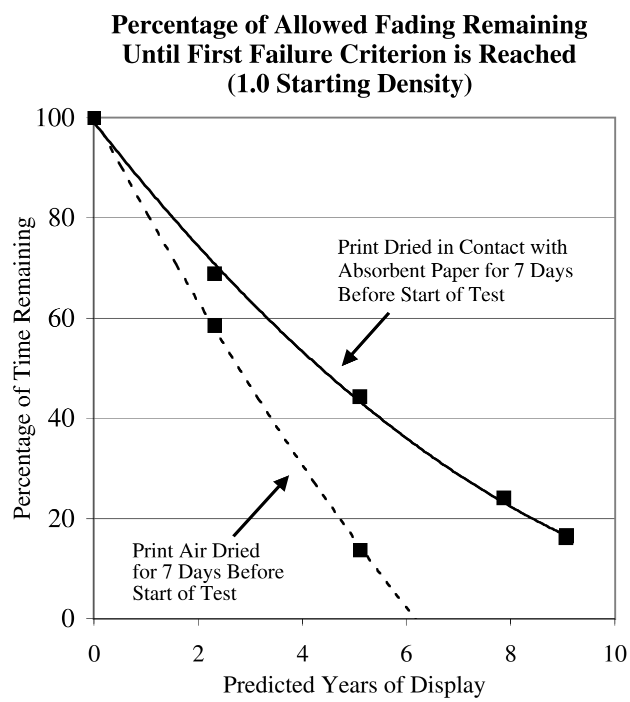

Figure 3. Effects of print drying method on "predicted years of display" for Epson PGPP/890 at 1.0 starting density (magenta).

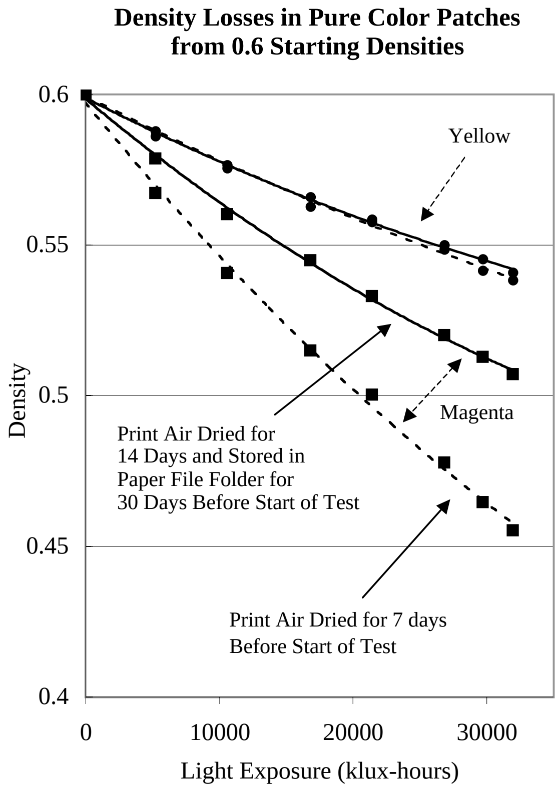

Figure 4. Influence of drying method and duration on the light stability of inkjet prints made with a swellable-polymer glossy photo paper and a 4-ink dye-based inkset. For clarity, the plot for the cyan ink has been omitted from this graph (the rate of cyan fading was reduced with the print stored in the paper folder for 30 days; however, the rate of cyan fading was not affected by the drying method nearly so much as was the rate of fading with the magenta ink).

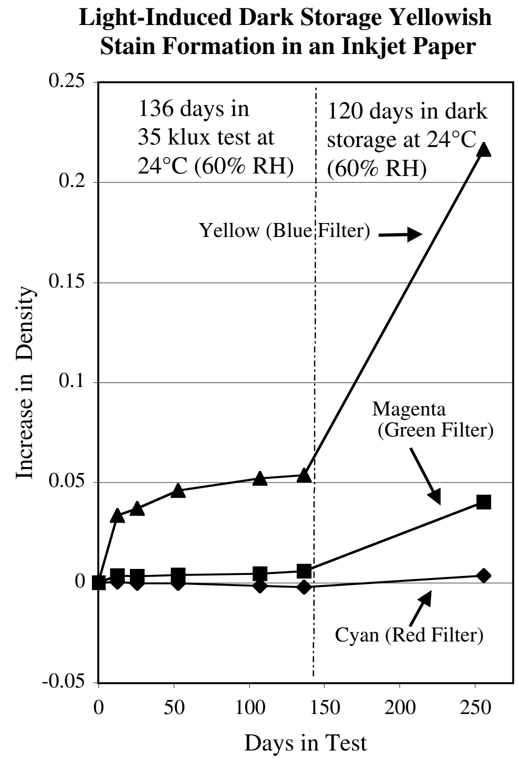

Figure 5. Light-induced yellowish stain formation with a microporous inkjet photo paper that had been exposed to 35 klux "bare-bulb" cool white fluorescent illumination in an accelerated fading test (there was no glass or plastic sheet between the print and the fluorescent lamps). Light-induced "dark storage" yellowish stain formation can also occur over time with traditional chromogenic color prints. This type of discoloration generally is more pronounced with materials exposed to the higher UV component of bare-bulb exposure.

test prints with a two-week drying period at 23°C and 60% RH prior to the start of accelerated light stability tests. However, the drying investigations reported here indicate that this clearly is not adequate and further research is being conducted to develop "accelerated" print drying/aging procedures that better correlate with long-term, real world results. Contact drying, moderately elevated temperature incubation under controlled humidity, and "drying" in elevated humidity conditions are being investigated.

Aqueous inkjet inks contain a significant percentage by weight of glycols and other high-boiling point solvents and humectants; after evaporation of the water component of the inks, the solvents and humectants remain; their presence in the ink receptive layers at the site of image dye molecules may negatively influence their light stability behavior.[3] It is hypothesized that over time these non-volatile ink components slowly diffuse into the media structure (or, in the case of "drying" in contact with paper, they may diffuse into adjacent absorbent materials), thus lowering their concentration in the print image receptive layers. With susceptible ink dyes, this may in turn reduce the rate of light fading. Other changes in the chemistry or morphology of the inks and ink receptive layer that occur over time may also be involved.

When inkjet prints are subjected to the high-intensity illumination employed in accelerated light stability tests, the print may suffer from light-induced yellowing that only manifests itself during a period of storage in the dark after the prints are removed from exposure to light. Bare-bulb fluorescent illumination, which contains significant UV radiation at 313nm, generally exacerbates this type of staining behavior. An example of this, with a microporous inkjet photo paper exposed to bare-bulb illumination, is shown in Figure 5. Traditional chromogenic color prints may be similarly affected.[4] Because short-term high-intensity light exposure tests may not yield meaningful data on long-term stain growth, further investigations into how to better model this behavior in a reasonably short time period are being undertaken.

Potential reciprocity failures in accelerated light fading tests are also a major concern.[5,6,7] Studies at Wilhelm Imaging Research are currently in progress with a variety of dye-based and pigmented inkjet ink/media combinations exposed to 1.0 klux illumination; glass-covered, glass with a 2 cm air gap between the print and glass to allow the free flow of air, and bare-bulb conditions are included. Thermal dye-transfer (dye-sub) prints, Fuji Pictrography prints, traditional chromogenic color prints, and other materials are being added to these tests and the results will be reported in the future. Data obtained to date with dye-based inkjet prints suggest that within the 35 klux/1.0 klux range of these tests, reciprocity failures as large as 2X to 4X may be encountered with both swellable-polymer and microporous media, with the prints fading both more rapidly and often with different color balance shifts at the 1.0 klux level than that which occurs at 35 klux. Both of these illumination conditions are maintained at 24°C and 60% RH. Bear in mind that 1.0 klux for 24 hours a day is an approximately 4X acceleration over the 450 lux for 12 hours per day used by Wilhelm Imaging Research as the standard display condition to which accelerated light stability data are extrapolated (and used in Table 1).

Other concerns involved in light stability testing are the humidity-fastness properties of prints and their susceptibility to gas-fading.[8] Ink/media combinations with poor humidity fastness can be subject to gradual changes in density and color balance and if such changes occur during the course of a light stability test, the light stability data will be compromised.[9] Likewise, microporous inkjet materials with a susceptibility to gas-fading may also yield misleading data if the air within a test facility contains ozone or other pollutants to which these materials are vulnerable; in some cases, reported light stability figures have unknowingly been compromised because of image deterioration caused by "gas-fading." The elimination of air contaminants from light stability test facilities is necessary if the "pure" light stability of a print material is to accurately be measured. (Wilhelm Imaging Research printing, test, and measurement facilities are maintained with extremely low levels of potentially damaging air contaminants.)

As a fortunate consequence of the heritage of chromogenic prints, where image dyes remain firmly anchored in swollen gelatin layers during wet processing and washing steps, traditional color photographs do not suffer from humidity-fastness problems. And once the wet gelatin layers are dried, they become excellent barriers to commonly encountered levels of air pollutants thereby protecting the underlying image dyes. For this reason, tests for these two major causes of dye-based inkjet print deterioration are not included in current ANSI and ISO image stability test methods standards.[10]

New ISO digital hardcopy image stability test methods standards are currently under development by ANSI/ISO Subcommittee IT9-3, a diverse international group of image stability experts and museum and archive specialists, and will address these shortcomings. Future ISO standards are expected to include tests for indoor light stability; humidity-fastness; thermal image degradation (dark aging); gas-fading; water-fastness; outdoor durability; and fingerprint susceptibility. All of these tests are necessary for a *full* characterization of the permanence of digitally-printed photographs.

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