Reciprocity Behavior in the Light Stability Testing of Inkjet Photographs

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Abstract

Accelerated light stability tests employ high-intensity illumination sources to speed the fading process and have been based on the assumption that light fading and light-induced staining reactions follow the reciprocity law; that is, for equivalent klux/hour light exposures, the amount of fading, changes in color balance, and development of d-min stain will be the same in accelerated light stability tests employing high-intensity illumination (e.g., 35 klux for 24 hours per day) as it is under low-level, ambient display conditions (e.g., 450 lux for 12 hours per day) as long as the temperature and relative humidity conditions are the same in both cases.

In this ongoing, long-term study, reciprocity behavior is evaluated using high-intensity 35 klux illumination and lower-intensity 1.0 klux fluorescent illumination. Both test environments are maintained at 24°C and 60% RH. Dye-based and pigmented inks printed on various types of inkjet photo media are included, along with representative traditional color and black-and-white photographic prints made with RC (polyethylene resin-coated paper) supports.

Potential problems in the design of reciprocity behavior tests for inkjet materials and interpretation of data from these tests are discussed.

Introduction

To the average consumer, an inkjet print made with coated inkjet photo papers is considered to be just as much a "photograph" as the ubiquitous chromogenic color prints made on RC photo papers that have been hanging on their walls, stored in albums and shoeboxes, and carried in wallets for a great many years. While the technology may have changed in a major way, the deeply felt reasons why people make and cherish photographs have not. As inkjet prints increasingly replace traditional color photographs in both consumer and commercial markets, people are displaying and storing these prints in the same ways that they previously did with traditional color photographs. Consumers want inkjet photographs to last as long, and hopefully longer, than traditional color photographs.

The question, "How long will a color print last?" is increasingly being asked. There are a number of compelling reasons for this suddenly heightened interest in image permanence. Until early 2000, just a little more than a year ago, when manufacturers began to bring improved products to the market, most inkjet photographs had very poor light stability and consumers and the press rather quickly became aware that the overall permanence of these prints was far inferior to that of traditional color photographs.[1-4]

Compared with the limited range of "standard" chromogenic color print papers offered by the world's four primary manufacturers, Kodak, Fuji, Konica, and Agfa, consumers are often bewildered by the almost limitless choice of inkjet printers and photo media, and by the unceasing flow of new and "improved" products. In the era of traditional color photography, very few individuals actually purchased color paper; instead, large centralized processing laboratories or minilabs in stores and malls made their prints for them. People usually accepted what they were offered.

Now people are buying inkjet printers and all sorts of photo media *themselves*. They look at a beautiful print emerging from their new inkjet printer and they have no idea how long it might last. This is all new and people have no long-term experience with these products on which to base an opinion as to how long they might last – even a vague opinion. It is not possible to tell how long a photograph will last simply by looking at it. Manufacturers' claims, to the extent that they exist at all, are often confusing and incomplete.

The adoption of in-studio inkjet printing by professional portrait and wedding photographers – which will be getting seriously underway by the end of 2001 – is certain to focus even more attention on the questions: "How long will they last? How does the permanence of inkjet photographs compare with that of traditional color photographs?" The answers to these questions come from accelerated tests that evaluate light stability on long-term display; humidity-fastness in a variety of storage and display environments; thermal, or "dark aging" stability; water-fastness; and resistance to gas fading. Obtaining meaningful data is not a simple matter; with inkjet materials, there are a number of "new" modes of potential image deterioration that have made the challenge of answering the question "How long will it last?" even more complex.

Accelerated Light Stability Tests

The use of accelerated light fading tests with color photographic materials has had a very long history. Ideally, of course, one would simply display test prints in a variety of home, office, commercial, and museum environments and patiently wait the many months or years necessary for the prints to reach predetermined endpoints for loss of density, changes in color balance, and growth of d-min stain. While such "natural aging tests" are extremely important as checks on the validity of data obtained from short-term accelerated tests, the long periods required for natural aging tests do not satisfy the needs of product research and development, nor can they furnish useful information to consumers. By the time meaningful data becomes available, the products in question have long become obsolete.

Reciprocity behavior tests employ two or more illumination levels (with even the lowest illumination level being higher than one would normally encounter in typical indoor display environments) in an attempt to determine if there is a significant deviation in the klux/hour-adjusted rate of fading, degree and direction of color balance changes, and stain growth between an accelerated high-intensity test and a more moderate, lower intensity test.[5–11]

Complications with long-term light stability tests may occur with inkjet prints because of humidity-fastness issues,[12–15] short-term color drift ("dry-down") effects,[16–17] and gas fading caused by low-level ozone and/or other atmospheric contaminants.[18–19] These image degradation processes usually proceed relatively slowly and as a result have greater effects – sometimes *much* greater effects – in long-term, low-intensity light stability tests than they do in short-term, high-intensity tests. For these reasons, air quality and the accurate control of temperature and relative humidity in the test environment are critical factors in light stability evaluations.

Reciprocity Behavior Tests

The two-illumination-level reciprocity behavior test method now in use at Wilhelm Imaging Research is described below. The test procedures were designed to separate the various effects of high and low-intensity illumination; the influence of air quality; short-term "dry-down;" and longer-term humidity-induced changes in image density and color balance. Fluorescent lamps (Philips Cool White HO lamps) in fixtures with white painted, open-air reflectors are used as the illumination source; there is no glass or plastic sheet over the lamps. The temperature at the sample-plane is maintained at 24°C by the use of fan-forced, re-circulating 60% RH air is directed between the fluorescent lamps and test prints. Without this rapid flow of cooling air, the nearby fluorescent lamps would significantly heat the test samples. This would lower the print moisture content, which could have significant restraining effects on rates of light fading.

High-Intensity 35 klux Test

1) Glass-Covered Condition. Prints are covered with a sheet of standard window glass, in direct contact with the print surface. This simulates the standard glass-framed print display condition commonly found in homes, offices, and museums.

2) Bare-Bulb Condition. Prints are exposed directly to fan-forced cooling air, with no glass or plastic sheet between the print samples and the lamps. This test is intended to roughly simulate the unframed, open-air display condition frequently found in homes and offices (including the attaching of prints to refrigerator doors with magnets!). Because glass effectively absorbs the 313nm mercury emission of the fluorescent lamps, the spectral distribution is different than that of the illuminate in No. 1 above; with most inkjet ink/media combinations, this results in somewhat more rapid fading and differences in the degree and direction of color balance shift.

3) Glass with Air Gap (optional). A glass sheet is placed 2 cm above the print surface in a manner that permits the fan-forced air to pass between the glass and the print surface. This test condition provides the same spectral distribution as No. 1 above, but with rapid air flow over the print surface, thus separating the contribution to fading and color balance shifts of the air in the test room.

Low-Intensity 1.0 klux Test

1) Glass-Covered Condition. Prints are covered with a sheet of standard window glass, in direct contact with the print surface.

2) Bare-Bulb Condition. Prints are exposed directly to fan-forced cooling air, with no glass or plastic sheet between the print samples and the lamps.

3) Glass with Air Gap. Unlike the high-intensity test described above, this test condition is mandatory in the 1.0 klux test. A glass sheet is

placed 2 cm above the print surface in a manner that permits ambient test room air to pass between the glass and the print surface

4) Print Sample Kept in Dark, Freely Exposed to Ambient Test Room Air. This sample is used to assess the contribution of room air to image changes when light is not involved.

5) Print Sample Kept in the Dark in a Heavy Paper Envelope Stored in the Test Room. This sample is used to provide an indication of long-term humidity-induced changes. The paper envelope should provide substantial protection against low-level ozone or other airborne contaminants.

6) Freezer Check Print. This sample is placed is a sealed polyethylene bag and stored in the dark in a freezer at –20°C (–4°F); a vapor-proof cabinet maintains the sample moisture content while in the freezer. This sample provides a long-term check on instrument calibration as well as a visual comparison with prints in the various tests.

Data from the high-intensity 35 klux tests is compared with that from the low-intensity 1.0 klux tests. Deviation in the fading rates, the degree and direction of color balance changes, and the growth of d-min stain will become apparent long before the first failure criteria endpoint is reached. For those materials that indicate a significant degree of reciprocity failure, the use of high-intensity data should be avoided for predicting long-term display life. Instead, one will have to base display stability projections on data obtained from the 1.0 klux test.

Figure 1 shows density losses for five ink/media combinations that resulted from 410 days of exposure to the high air flow in a 24°C and 60% RH test room at Wilhelm Imaging Research. The very low 80 lux glass-filtered illumination that prints were exposed to during the course of this test can be considered to have made only a minor contribution. It can be seen that although the density losses observed with Epson Premium Glossy Photo Paper (original type) are not insignificant, they are far less than have been reported by others who have conducted much less stringent ambient air exposure tests. The WIR data for this particular microporous paper and ink combination, which field reports have shown to have a high sensitivity to ozone and/or other airborne contaminants, indicates that the air in the WIR laboratory building has very low levels of the contaminants which can cause rapid fading of this ink/media combination. This underscores the critical role

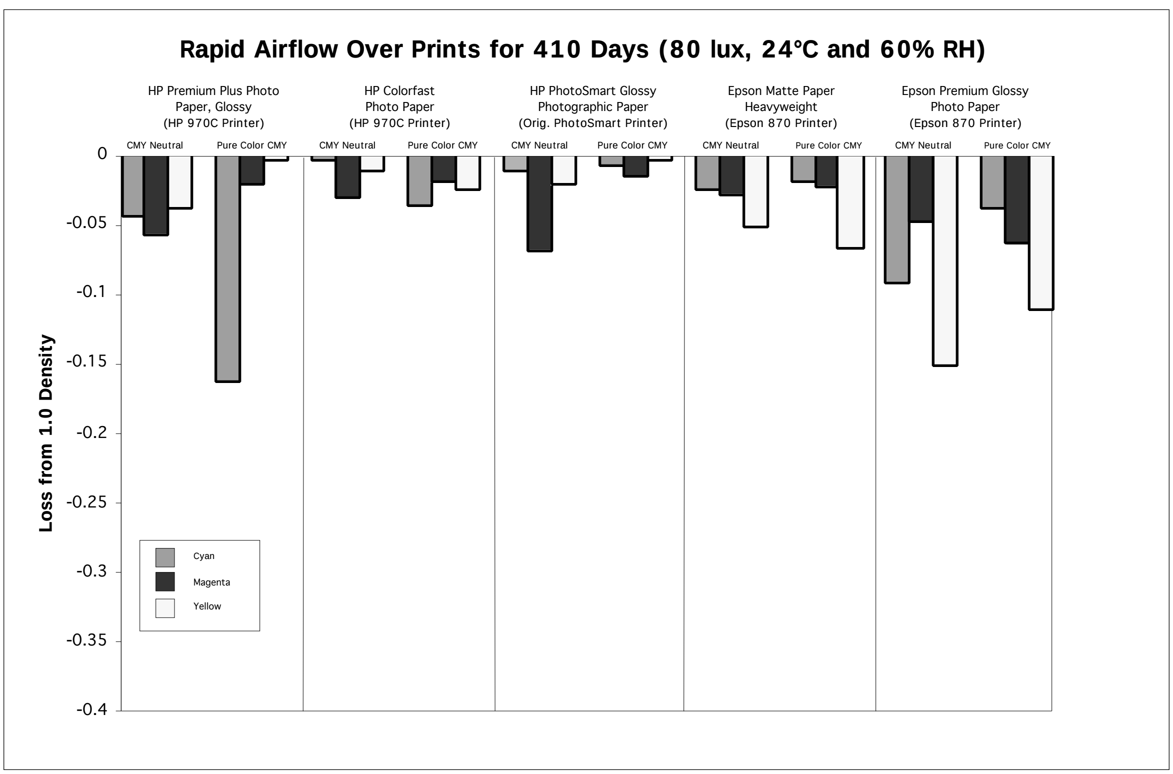

Figure 1

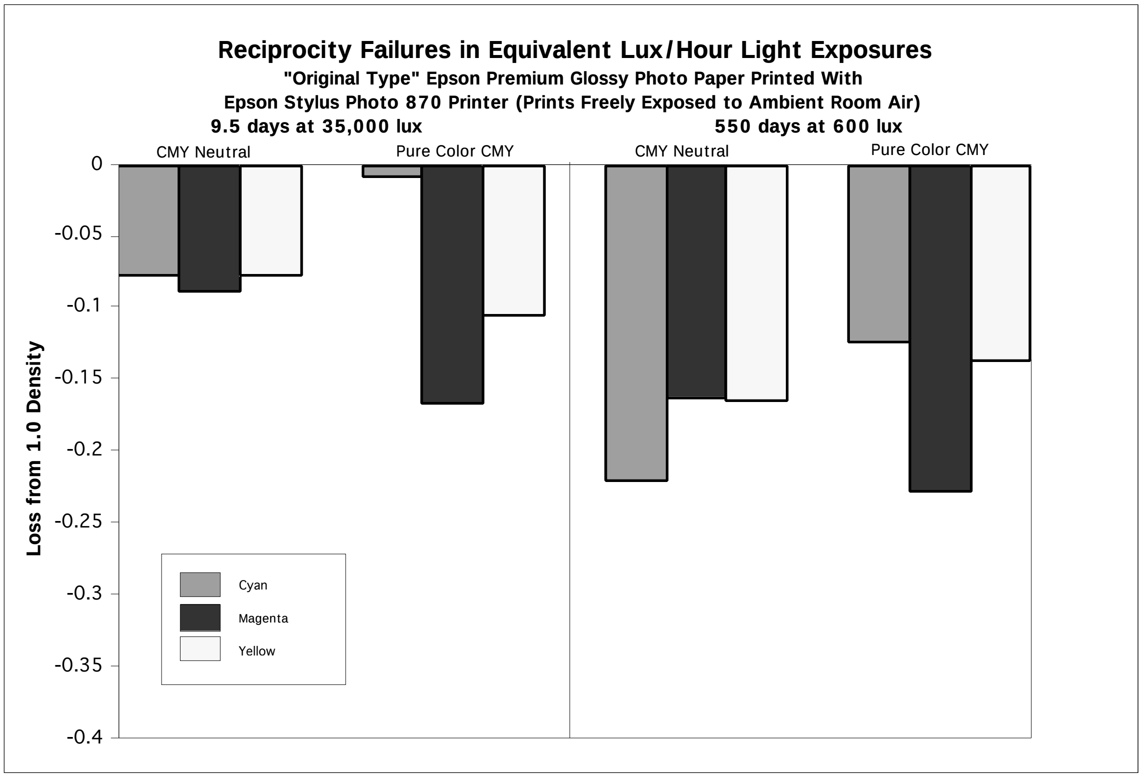

Figure 2

of air quality in an image stability test facility and suggests that it may be very difficult to achieve consistent test results among different laboratories when prints are exposed to ambient air during a test period.

Figure 2 is a comparison of “original type” Epson Premium Glossy Photo Paper in the standard Wilhelm Imaging Research 35 klux test condition and with a 600 lux test conducted for 550 days in a 24°C and 60% RH workroom in one of our buildings. The workroom is ventilated with circulating air from the rest of the building, which has a modest amount of air exchange with fresh outdoor air. This example indicates the probability of a modest contribution of gas fading to measured overall fading (especially of the cyan ink). However, when evaluated with the weighted failure criteria set employed by WIR, the increased rate of cyan fading will not trigger the first end point in the 35 klux sample. The first endpoint to be reached by the 600 lux sample is expected to be the 25% density loss of pure color magenta – that same as was the case with the 35 klux test condition. When compared with the high-intensity 35 klux data, the calculated reciprocity failure will be about 1.4. That is, at 600 lux this particular ink/media combination will reach its first endpoint about 1.4 X sooner than predicated by the high-intensity test. This is a modest reciprocity failure, similar to that experienced with many chromogenic color print materials from the 1980’s and early 1990’s.

Conclusion

What constitutes “normal” indoor air quality and, in a light stability test, how to deal with the component of image deterioration caused by airborne contaminants are as yet unanswered questions. Many of these concerns are new to inkjet printing – traditional color photographs are not subject to humidity-fastness problems nor to short-term color drift. Traditional color photographs have, in a wide range of user environments, proven to be highly resistant to commonly encountered indoor levels of air pollutants.

The “refrigerator door” display condition in which unframed prints are attached to refrigerator doors with magnetic materials is indeed one of the most common modes of display found in homes; these prints are exposed to the freely circulating air found in kitchens (air that at times may contain significant levels of “cooking fumes,” moisture from boiling water, and, if a gas stove is present, by-products of gas combustion). Recent experience with inkjet prints made with dye-based inks and microporous photo media which in some locations suffered catastrophic loss of cyan dye – occasionally in only a matter of days – has focused great attention on the gas fading problem.

In the image permanence research field, susceptibility of inkjet prints to gas fading – along with humidity-fastness shortcomings and the limited light stability of many dye-based inkjet photo materials – have underscored the importance of recognizing that in the real world, photographs are stored and displayed in a very wide range of environments. Image stability test methods must account for this reality – and they need to do so in the framework of the full range of environments found in all parts of the inhabited world, including those areas where air conditioning and air-filtration systems are the exception, not the norm.

In an attempt to address these problems, and to bring a degree of standardization to the test procedures and reporting methods employed by manufacturers and others worldwide, ANSI/ISO Subcommittee IT9-3 is currently working to develop a new and much more comprehensive digital hardcopy test methods standard for inkjet and other digital imaging materials.

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Article by Henry Wilhelm and Mark McCormick-Goodhart (Wilhelm Imaging Research, Inc.) entitled: “Reciprocity Behavior in the Light Stability Testing of Inkjet Photographs” appeared on pages 197–202 in:

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