# Humidity-Induced Color Changes and Ink Migration Effects in Inkjet Photographs in Real-World Environmental Conditions

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## Abstract

This paper examines some of the long-term keeping properties exhibited by recently marketed ink jet media/ink formulations when they are exposed to moderate to high humidity conditions similar to those that can be found in real-world display and photo album storage environments. Various ink/media formulations have been subjected to humidity levels ranging from 60% to 80% RH at near-ambient room temperature environments (27 degrees Celsius) and examined for color changes over time. Test samples include both dye-based and pigment-based systems.

## Introduction

Inkjet photography is a specialized but rapidly growing segment of the overall inkjet printing market. It can be readily distinguished from the broader inkjet marketplace because the image quality requirements are much more demanding. A number of inkjet printers for home and commercial use already meet or exceed the perceived initial image quality of traditional photo lab prints. While the initial image quality of an inkjet photograph must compete with traditional silver halide photography in terms of overall color, tone, sharpness, and uniformity, the retention of image quality over time is also a critical requirement. Image permanence is especially important in professional segments of the marketplace such as the portrait and wedding field. This paper examines the humidity-fastness of three currently marketed desktop printers aimed at the photo market. One printer uses a four-ink dye-based formulation. Another printer uses a six-ink dye-based formulation (light cyan and light magenta added). The pigmented ink printer also uses a six-ink formulation. In each case the manufacturer's recommended ink and paper were tested. We refer to these printer/ink/paper combinations as System A, System B, and System C.

## Experimental

System A is the four-ink dye-based printer. The manufacturer's standard dye set and premium photo paper were tested. System B used the manufacturer recommended six-ink formulation and a coated matte-finish photo paper. This system is marketed as a photo printer, and the paper is one preferred by many photographers. System C is a six-ink desktop printer using a fully pigmented ink set and aimed specifically at the serious amateur and professional photo market. The printer manufacturer's semi-gloss photo paper was selected for testing. The ink/paper combination of System C has light-fastness properties in excess of one hundred years according to recent tests conducted at Wilhelm Imaging Research. The ratings are based on light exposure of 450 lux for 12 hours per day, and the tests are ongoing. For this display life prediction to to be realized in practice, humidity-fastness, thermal stability, and resistance to airborne pollutants must also be excellent, otherwise the prints could deteriorate prematurely due to the weakest link. We examined the humidity-fastness in this study.

Prints were made with each matched system under office conditions of 22°C and 60% relative humidity. Prints made by Systems A and B received additional drying time at 60% RH for about one month before the first reference measurements were made. Tests with prints made by System C were started immediately after printing. The prints were then placed in environmental chambers that are maintained at slightly above ambient temperature (27°C). A small fan provided circulation and prevented mold growth at the higher humidity levels. Three chambers were set to 60%, 70%, and 80% RH respectively and regulated to plus or minus 1% RH. The chambers were accurately calibrated with a General Eastern chilled mirror hygrometer. Each print is a target image consisting of 90 patches. The target contains neutral and color patches of cyan, magenta, yellow, black, red, green, and blue that are printed with optical densities of 0.25, 0.5, 0.6, 0.7, 0.9, 1.0, 1.1, and maximum density. All three printers are CMY devices, only using the black ink in the highest densities. Neutral patches print using C, M, and Y inks only except at the maximum density patch. For example, the CMY patch at 0.6 had initial Status A densities for the red, green, and blue filter values equal to 0.6. Similarly, a blue patch at 1.0 density had Status A density values for red and green filters equal to 1.0 while the red ink patches measured 1.0 for the green and blue filter values. For this type of printer the black patches on the target also print as CMY neutral patches and therefore serve as replicates of the CMY patches. Humidity-induced color changes were then

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measured using CIELAB colorimetry. The L*A*B* values of all 90 patches were measured prior to starting each humidity test and then at selected time intervals. Delta E was then determined between the reference measurements and the corresponding targets after an elapsed time at a constant specified humidity level. The results are presented using two methods of interpretation. The first method plots Delta E versus the initial Status A density of the neutral, cyan, magenta, yellow, blue, green, and red patches.[1] This graphical assessment allows the behavior of individual inks to be characterized including interactions when more than one ink is present as is the case with the blue, green, red, and neutral patches. The Delta E values for 56 individual patches are plotted on this type of graph. The second method plots the average Delta E versus Time of all 90 patches and also the maximum Delta E versus Time determined by one of the 90 patches.

## Results

Samples from Systems A, B, and C were in test for 70 days at the three chosen humidity levels of 60%, 70%, and 80% RH. This test time was sufficient to induce major color changes in Systems A and B. It also demonstrated the superiority of System C. Figures 1 and 2 show the behavior of System A after 70 days at 60% RH and just 7 days at 80% RH. The magenta dye migrates significantly, causing large changes in colors that contain magenta. A visual assessment of this paper reveals that much of the migration is lateral in the image which causes text bleeding with magenta fringes and "dot gain" in the highlight regions of the print. Note the high Delta E in the lower density magenta and red patches.

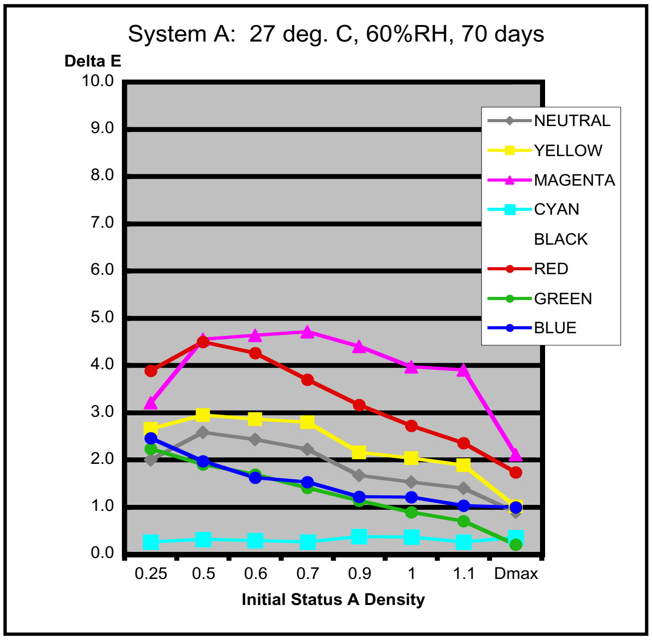

*Figure 1. 70 days at 60% RH for System A*

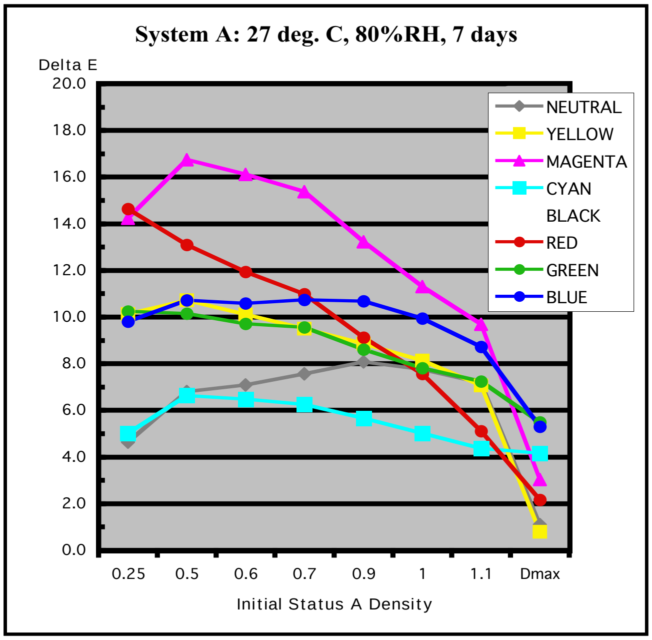

*Figure 2. Seven days at 80% RH for System A*

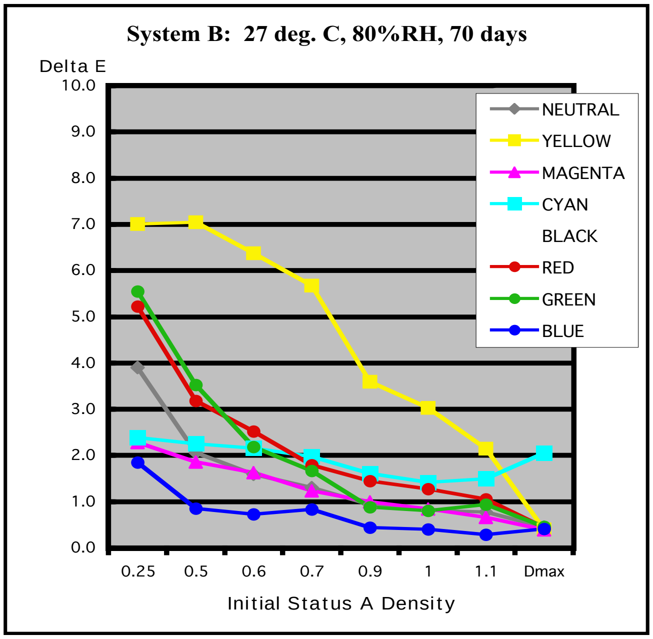

*Figure 3. 70 days at 80% RH for System B*

Figure 3 shows the behavior of System B at the high relative humidity level of 80% RH after 70 days in test. This dye and paper combination was reasonably stable at, or below, 70% RH but ran into trouble at 80% RH (see Table 1). In this case the yellow dye diffused more rapidly than the cyan and magenta dyes. Tests of the System B printer with another of the manufacturer's recommended papers produced a different result where all dyes migrated more uniformly at 80% RH. These facts suggest the importance of designing a matched dye and paper set where the dyes

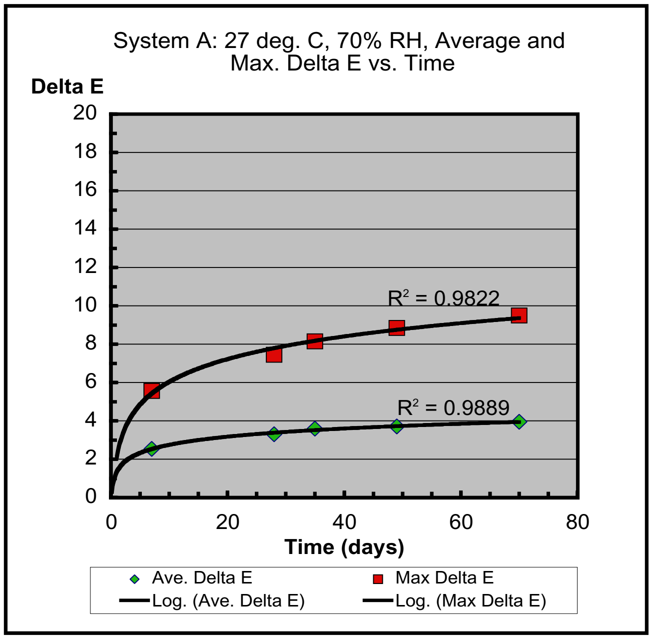

*Figure 4. Delta E data collected for System A at 70% RH*

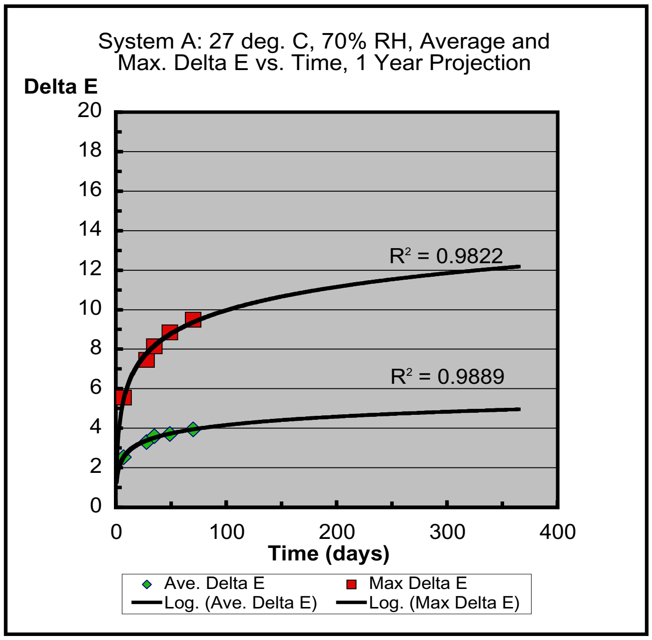

*Figure 5. One year prediction of Delta E color change based on logarithmic fit to data collected for System A at 70% RH*

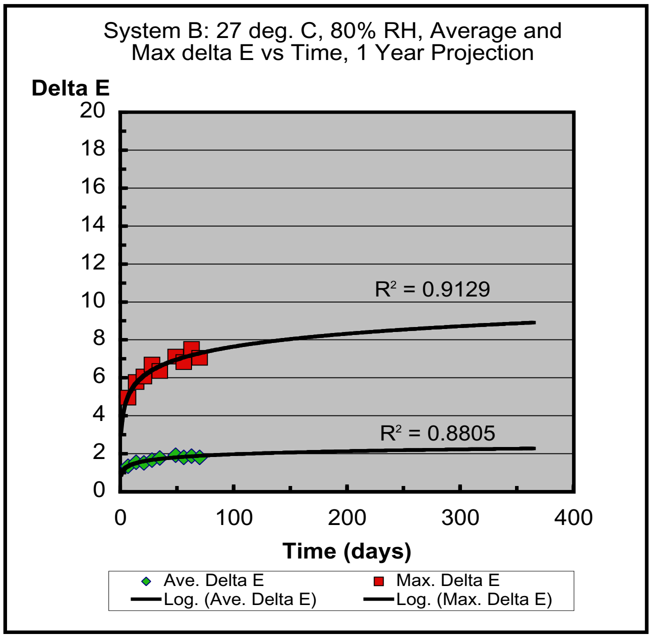

*Figure 6. One year prediction of Delta E color change based on logarithmic fit to data collected for System B at 80% RH*

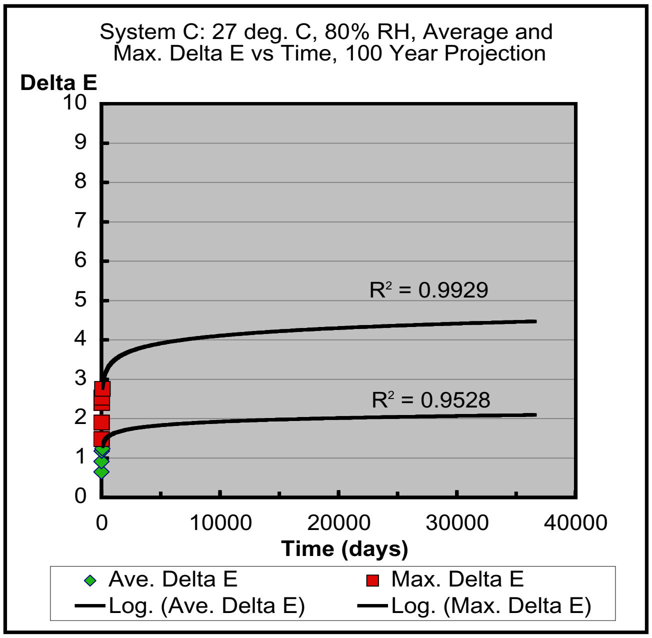

*Figure 7. One hundred year prediction of Delta E color change based on logarithmic fit to data collected for System B at 80% RH*

are properly mordanted to prevent diffusion at elevated humidity.

Colorimetric data was collected at various time intervals for all 90 patches of each target print. The maximum Delta E change and the average Delta E change for all 90 patches were then plotted as a function of time. A logarithmic function was determined to fit all the data well. R-squared values in excess of 0.95 were typical except for the matte finish photo paper of System B where $R^2$ was approximately 0.88 to 0.91. The logarithmic curve fit enabled a forward projection of the changes that are likely to occur over time. Figures 4-7 illustrate these results, and Table 1 is a compilation of the predicted behavior of Systems A, B, and C over time.

## Conclusion

The pigmented ink set of System C showed excellent overall humidity-fastness. The maximum Delta E for this system was predicted to remain less than 5 over a one hundred year time span at 80% relative humidity. The high solvent retention immediately after printing probably accounts for the maximum Delta E shift of approximately 2.0 observed on the first day, but this degree of color shift is acceptable for even demanding markets such as contract proofing. These test results indicate that the pigment particles have enough mass or adhesion to remain immobile when high levels of free water are subsequently absorbed by the print. In reality such long-term keeping at elevated humidity would likely incur mold and mildew growth in an album keeping environment because static air conditions encourage such growth. In this respect the substrate and coating of this inkjet print would probably fair no worse than traditional photographs that employ a gelatin binder. The important aspect of this finding is that System C is an exceptionally stable system, and it demonstrates that inkjet technology is indeed capable of meeting the demanding requirements of photographic permanence.

On the other hand, System A reveals the other extreme situation for today's currently marketed products. The dyes used in System A and in particular the magenta dye are so mobile within the paper that significant dye migration and image bleeding will occur within a short time frame at commonly encountered relative humidity levels of 60% RH. Indeed, numerous inkjet prints made on various printer/ink/media combinations that were kept in our office environment during previous summers showed obvious text bleeding and color fringing problems. We had never encountered these issues with traditional photographic media. Prior to an upgrade in early 1999 of our building's HVAC system, the summertime office conditions would routinely reach 65 to 75% RH. Adequate air movement prevented mold and mildew, but many inkjet prints were adversely affected, and these observations were the impetus to begin the humidity-fastness research.

Additional data we have collected at 50% RH shows that prints made by System A would not exhibit humidity-induced changes for ten years or more if maintained at 50% RH or less. However, this is an unreasonable expectation in the real world. Typical HVAC systems do not dehumidify buildings situated in humid summer climates lower than approximately 60% RH.

The performance of System B is significantly better than System A, but this situation is still marginal for use as a photographic print product. Table 1 shows that System B is reasonably stable at 70% RH, but high mobility of the yellow dye occurs within the 70-80% RH range. Modern HVAC systems can provide photo album storage environments that will keep the System B prints in good condition, but there is not much safety margin because short term excursions to over 70% RH happen in the real world with some regularity. Such indoor environmental conditions are routinely encountered in non air-conditioned buildings.

Table 1: Predicted Maximum and Average Color Changes on 90 Patch Test Target Over Time.

| | **System A**<br>1 year | **System B** | | **System C**<br>100 Years |
|---|---|---|---|---|
| | | 1 year | 10 year | |
| **60% RH** | Max. ΔE<br>6<br>Ave. ΔE<br>3 | | Max. ΔE<br><1<br>Ave. ΔE<br><1 | |
| **70% RH** | Max. ΔE<br>12<br>Ave. ΔE<br>4.5 | | Max. ΔE<br>3<br>Ave. ΔE<br><2 | |
| **80% RH** | Max. ΔE<br>>20<br>Ave. ΔE<br>10 | Max. ΔE<br>9<br>Ave. ΔE<br>2 | Max. ΔE<br>11.5<br>Ave. ΔE<br>3 | Max. ΔE<br>4.5*<br>Ave. ΔE<br>2* |

* Initial 24 hour dry down after printing accounts for average ΔE =0.6, maximum ΔE =1.9

In summary, our findings suggest an inherent advantage of pigments over dyes with regard to humidity-fastness. However, by comparing the results of System A to System B, it is reasonable to expect that research and development of dye-based inkjet systems can improve the humidity-fastness of the product by proper selection and mordanting or anchoring of the dyes within a specifically chosen substrate. Matched ink and media are clearly a requirement for dye-based inkjet prints in the photographic marketplace. Pigment-based systems may have more substrate latitude with regard to image permanence, but color gamut and surface uniformity characteristics can be optimized by ink/substrate selection. Thus, matched ink/media are an important factor for pigment-based inkjet technology as well.

## References

1. Henry Wilhelm and Mark McCormick-Goodhart, "An Overview of the Permanence of Inkjet Prints Compared with Traditional Color Prints", *IS&T's Eleventh International Symposium on Photofinishing Technologies, Final Program and Proceedings,* IS&T, Springfield, VA, January 2000, pp. 34-39.

Article by Mark McCormick-Goodhart and Henry Wilhelm (Wilhelm Imaging Research, Inc.) entitled: "Humidity-Induced Color Changes and Ink Migration Effects in Inkjet Photographs in Real-World Environmental Conditions" appeared on pages 74–77 in:

# Final Program and Proceedings of:

# IS&T's NIP16: International Conference on Digital Printing Technologies

**ISBN: 0-89208-230-5**

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October 15–20, 2000
The Westin Bayshore Hotel
Vancouver, B.C., Canada

Published by:

IS&T–The Society for Imaging Science and Technology
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Springfield, Virginia 22151 U.S.A.
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This document originated at <www.wilhelm-research.com> File name: <Wilhelm_IS&T_Paper_Oct2000.pdf>