The Influence of Relative Humidity on Short-Term Color Drift in Inkjet Prints

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Abstract

The color drift occurring in inkjet prints during the hours, days, and weeks after printing can be significantly influenced by the relative humidity of the environment in which the print resides. Especially for dye-based systems, the amount of color drift caused by real world humidity levels (e.g., 65–80% RH) is great enough to affect the accuracy of color management profiles if they are made too soon after printing and/or at humidity levels which differ greatly from later print making conditions. The short term drift or "dry-down" behavior reported in this paper also indicates the need for careful print conditioning procedures or data compensation techniques when designing image permanence testing procedures that are intended to examine other modes of color change such as light-fastness or thermal aging. Lastly, and perhaps most importantly, when a failure criterion for allowable color change over time is chosen with regard to assessing the long term humidity-fastness of a product, the inclusion or exclusion of the short term drift component can lead to major discrepancies in the life expectancy prediction.

Introduction

A desirable characteristic of inkjet prints is that they be "dry to the touch" very quickly after printing and exhibit no signs of blocking or sticking to other prints. This attribute is one factor that has led to the increased use of microporous coatings. Although inkjet prints may appear to be fully dry to the user, the color balance and density of an inkjet print can continue to change significantly in the days or weeks following the time of printing. This leads to ambiguity about what constitutes the finished print, one that may be safely handled but also used to confidently judge final color balance and density. The color proofing market has particularly demanding requirements, but minimizing short term drift is important for the professional and amatuer photography market as well. The ideal situation is to have an inkjet system that exhibits little short term drift as well as excellent long term resistance to high humidity environments. Such a system is shown in Figure 1, and it illustrates that some inkjet prints can indeed meet stringent requirements for both short term and long term humidity-fastness. On the other hand, when colors continue to change after the printer has ejected the print and after the user can safely touch the print surface, then the more advanced or professional user may find the need to wait an extended time interval before color quality of the finished print can be critically judged. Another complication is that individual colors can change at different rates depending on the humidity level of the environment in which the print resides. The colorimetric data required for building an accurate color profile of the system will be influenced by the humidity level to which the print is exposed as well as the time elapsed after printing if the system is sensitive to humidity-related color drift. In extreme cases, the humidity of the surrounding environment can lead to a marked and unacceptable decline in print quality due to lateral bleeding or smearing of line and type quality in addition to an overall change in color balance. None of the data shown in this paper were derived from samples that had objectionable losses in image sharpness or text quality although in some cases subtle changes were observed. Changes in color balance occur from vertical as well as lateral migration of the colorants while line and text quality and overall print sharpness decline primarily due to lateral migration.

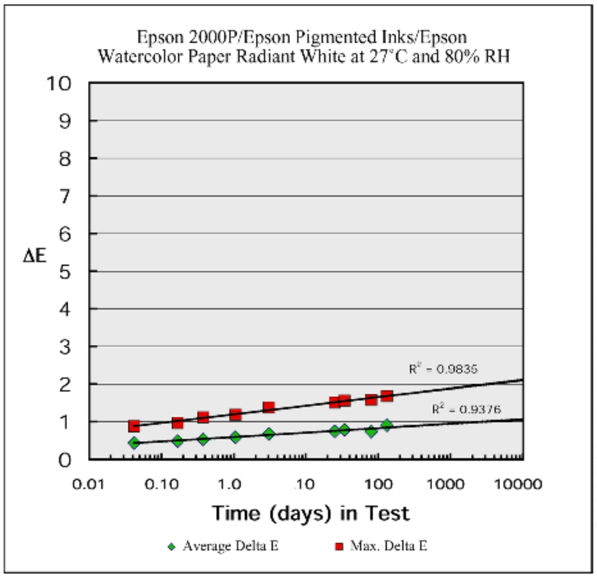


Figure 1.

Experimental

In earlier work, we reported that humidity-fastness behavior was successfully modelled using a logarithmic fit of the data when samples were aged under tightly controlled and steady-state humidity levels. In this study all prints were made with each matched system under office conditions of 22°C and 60% relative humidity. The prints were immediately transferred from the printer to humidity controlled chambers where the prints were allowed to "dry" for one hour. Reference color measurements of a 90 color patch target were then made using a Gretag/Macbeth Spectrolino, and further measurements were repeated over time. Other than the brief measurement time on the Spectrolino (at 22C/60% RH) all prints were kept at their respective constant relative humidity conditions. The environmental chambers were maintained at 27C d ± 0.2C and RH was controlled within ± 2% RH using microclimate methods. A small fan provided circulation and prevented mold growth at higher humidities. 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 printers used in this study 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 would have Status A density values for red and green filters equal to 1.0 while the red color patches would measure 1.0 for the green and blue filter values.

ΔE values were determined between the reference measurements, which as noted previously were taken one hour after printing, and the subsequent sample measurements. The data are presaented using two types of graphical analyses. One type plots ΔE versus the initial Status A density of the neutral, cyan, magenta, yellow, blue, green, and red patches. This graphical assessment allows the beha—vior 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 ΔE values for 56 individual patches are plotted_ on this type of graph. The other type of graph plots the average ΔE versus time for all 90 patches and also the maximum ΔE versus time determined by one of the 90 patches. The time sducale is logarithmic. The maximum ΔE for just the neutral patches and excluding the maximum density value is also shown on this type of graph.

The retention of proper color balance in neutral image areas is especially important because the human observer tolerates less change in neutrals and other memory colors. It is important to remember that ΔE is a measure of perceptual difference of colors rather than perceptual tolerance to changes in colori. For example, photographers will tolerate little change in the neutral scale or strong memory colors such as skin tones. Other memory colors such as blue skies and green foliage have wider latitude for visual change while non-memory colors require a comarative reference in order to judge their accuracy.

In our humidity-fastness research to date we have not yet assigned a specific failure criterion to the tests. However, we believe that ΔE value of 8 in the neutral and near neutral values of a photograph would represent a noticeable and objectionable change for most photographers and artists without a reference print for comparison. During printmaking sessions when comparison prints are available, artists and photographers will often choose the optimum print based on ΔE differences equal to two or three between certain tones in the comparison prints.

Results and Discussion

Figures 2 through 9 illustrate the performance of Kodak Premium Picture Paper – High Gloss printed on the Kodak Personal PictureMaker 200 printer (labeled PPM 200) with Kodak inks. Data for 60%, 65%, 75%, and 80% relative humidity are presented. This inkjet system produces prints on this paper that exceed twenty-five years of predicted display life (tests ongoing) in light-fastness tests conducted by Wilhelm Imaging Research, Inc. (WIR). WIR uses 450 Lux for 12 hours per day at 75F/60% RH as the reporting standard. Figure 2 shows that at 60% RH the maximum ΔE equaled approximately 5 after 24 hours while average ΔE was less than 2 and little further change is projected to occur for 10,000 days (27 years). An interesting aspect of this graph is the behavior of the neutral patches. The maximum ΔE of the neut aral patches other than the Dmax patch rises at a faster rate and is projected to overtake the maximum ΔE curve at 10,000 days. The data in Figure 3 reveals that the neutral patches are changing most between 0.6 and 0.9 optical density while the maximum ΔE during the first 97 days of testing occurred in the Dmax neutral patch. This can be interpreted to mean that in the first 97 days under test the patch that changed most will not necessarily continue to remain the most changed over time. Other colors may reach or exceed that patch and then become the maximum ΔE value that gets plotted in Figure 2. A forward projection of the maximum ΔE curve will therefore have more possibility for error than the average ΔE curve because it may switch patches whereas average ΔE tracks the full set. Nevertheless, plotting maximum ΔE is useful because it gives an indication of the range of values which are averaged to form the average ΔE plot. Additionally, the data in Figure 2 predicts that when carefully kept at 60% RH or less and ambient room temperature, the Kodak print will not experience humidity-induced changes that undermine the validity of the predicted 25-plus year display life as determined in a light-fastness test.

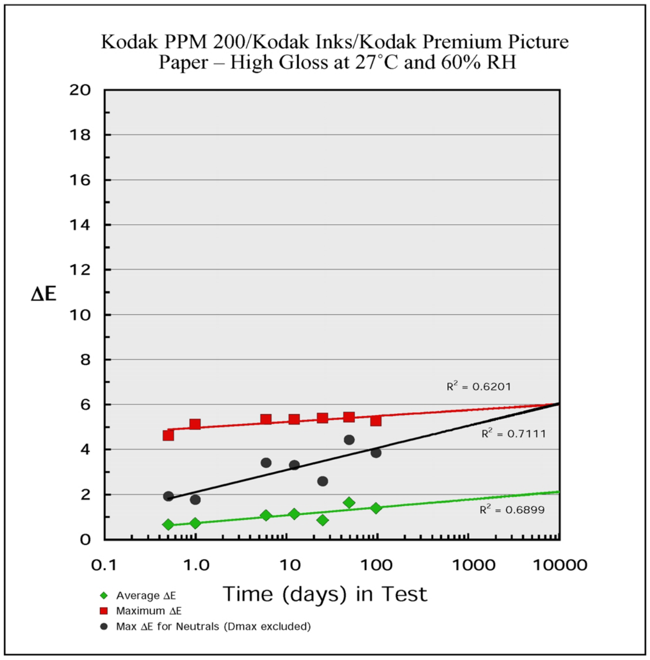


Figure 2.

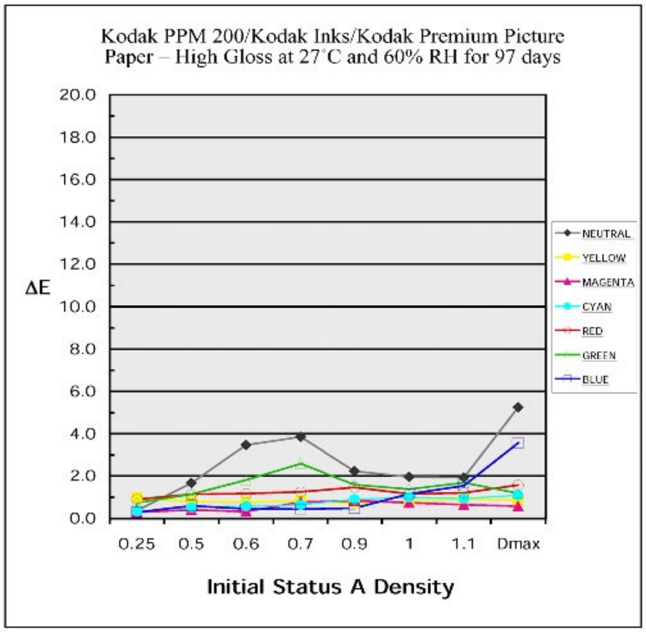


Figure 3.

Figures 4 and 5 show the Kodak PPM 200 system behavior at 65% RH. If one were to use a failure criterion of ΔE = 8 for neutral patches then this paper would fail in less than one year when compared to a reference print having been judged for proper color balance within an hour after printing (i.e., our colorimetric reference data). Yet due to the logarithmic nature of the humidity-induced color change, a printmaker who waits one week before judging final color balance would now define a new reference for comparison. This new reference print will not undergo further ΔE = 8 changes for over three decades. Surprisingly, by including the short term drift component in the amount of observed change one can conclude that the print will fail in less than one year or, by excluding short term drift, it will therefore last more than thirty years! Figures 6 and 7 show the Kodak system behavior at 75% RH. If the reference point is taken to be one hour after printing, then the print reaches a ΔE = 8 neutral patch failure in just one week. An additional ΔE = 8 will occur in about 1000 days (2.7 years). At 80% RH the Kodak print exceeds the ΔE = 8 neutral patch failure criterionmea in less than 12 hours. The change occurs at print density levels between 0.9 and 1.1 as shown in Figure 8. Comparing Figure 8 to Figure 9 we observe that low density neutral patches change less than higher density neutrals during the beginning hours but catch up after one week. This behavior was also observed in the early days of the 75% RH test. The significance of this data is that it reveals both short term drift which would impair the user's ability to profile the system and also a high vulnerability to brief encounters with high humidity levels for prints that are otherwise safely stored for years at less than or equal to the 60% RH. Most users would not experience the twenty-five year display life predicted by light-fastness testing because the print would likely undergo serious color balance shifts due to the very poor resistance to high humidity. Although a print framed under glass will benefit by the moisture buffering properties of matting and framing, the long term protection is probably not adequate unless a high moisture vapor barrier is also used. Pictures stored in a photo album would also be susceptible to color shifts that preferentially affect the edges. The edges of the album are less protected from humidity fluctuations than the center by the moisture buffering properties of the album. Figures 10 through 13 illustrate the behavior of Epson Premium Glossy Photo Paper printed with Epson inks on an Epson Stylus Photo 870 printer. This paper was introduced in February, 2000 and has a display life rating of 9 to 10 years in WIR light-fastness tests which use 450 Lux for 12 hours per day at 75F/60% RH as the reporting standard (this paper has since been reformulated to improve gas fading resistance). Figures 10 and 11 show the behavior of the system when the print drying and storage conditions are maintained at a very low humidity level of 15% RH. Continuous exposure to 80% RH is plotted in Figures 12 and 13. In these tests, the low RH environment for the most part stalls the colorant migration. However, the high ink loading in the high density patches retains enough initial moisture to allow some migration in the early stages of drying. The low humidity condition is transient because it is not possible to maintain in real world environments. Also, it is perhaps counterintuitive that "dry" environmental conditions don't allow the print to reach a finished state as easily as higher humidity conditions when the goal is to judge "final" color balance as soon as possible. A better strategy is to allow moderate or higher humidity conditions which will hasten

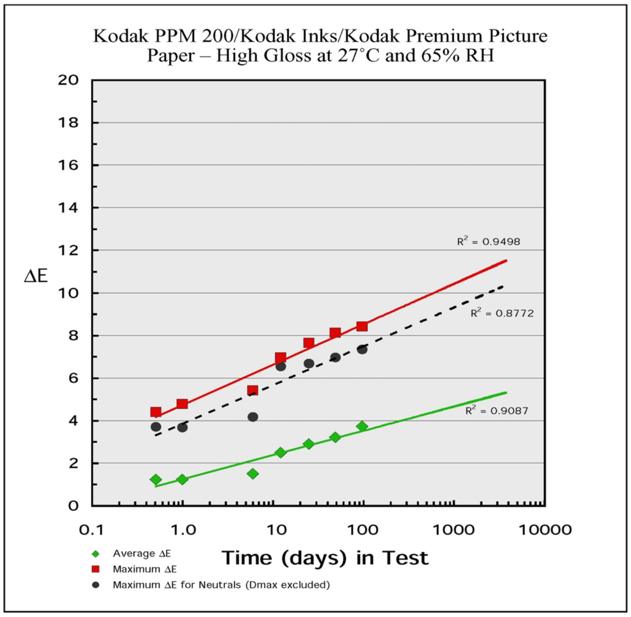
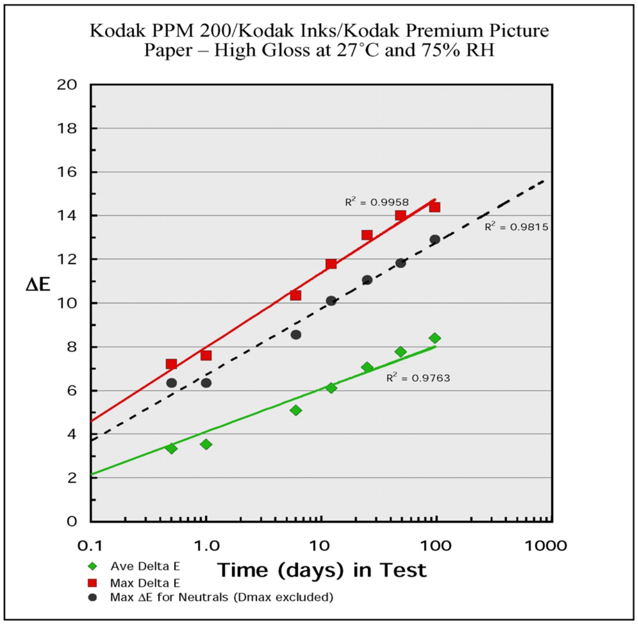


Figure 4.



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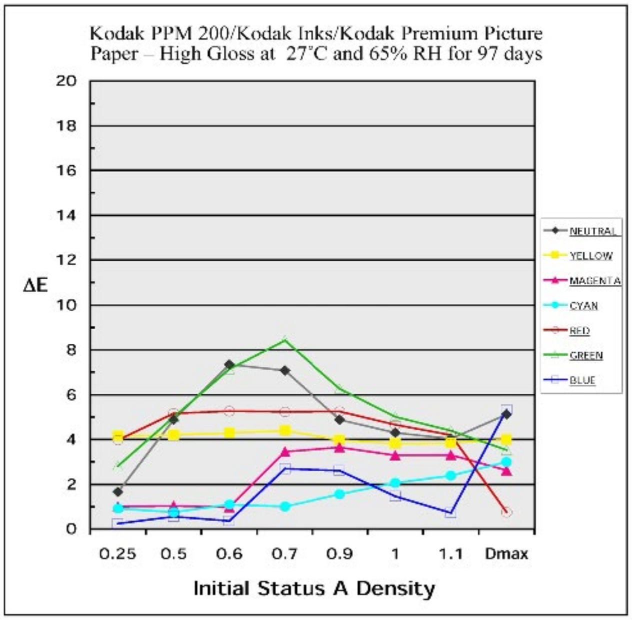

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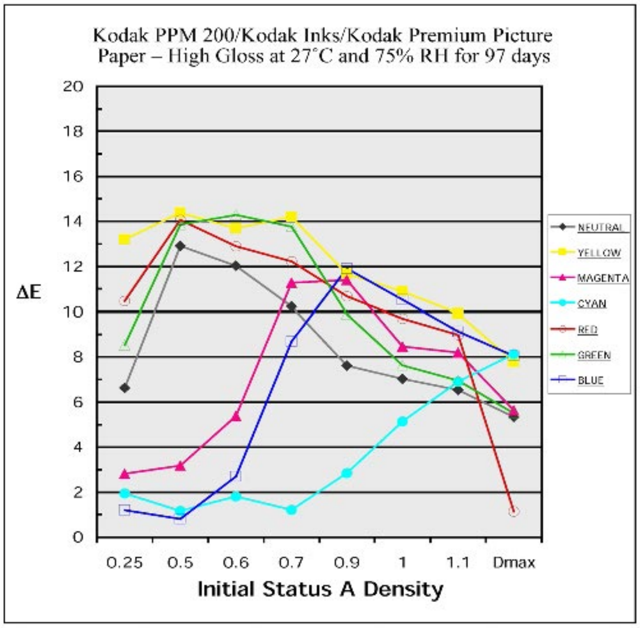

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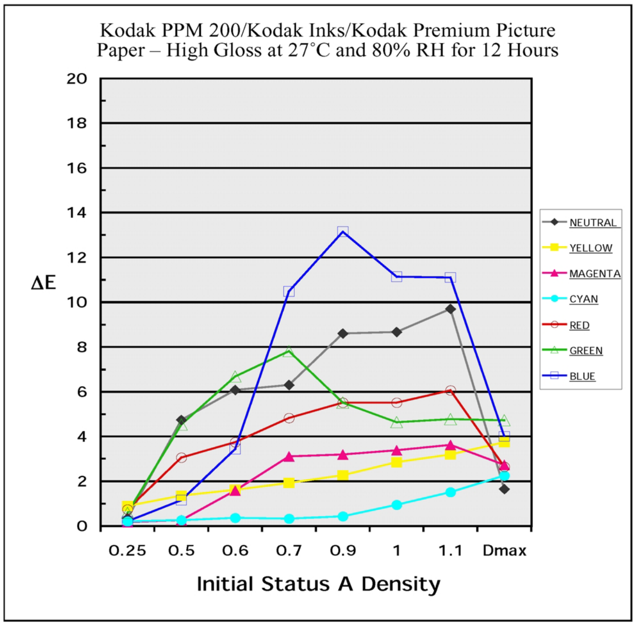

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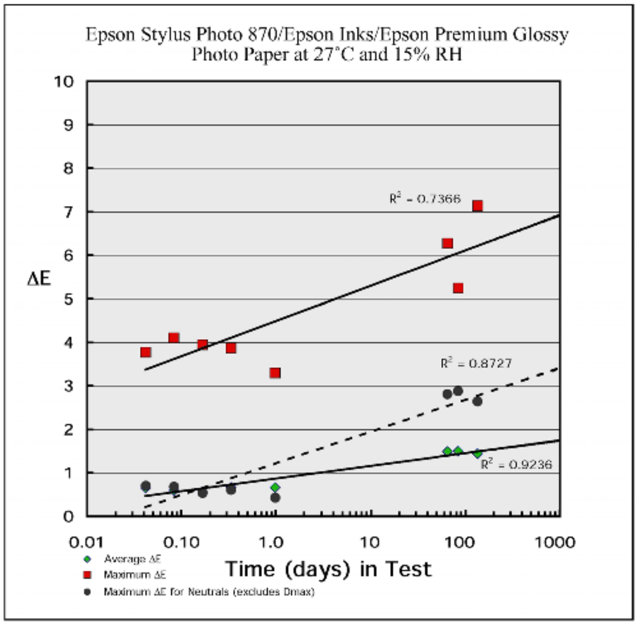

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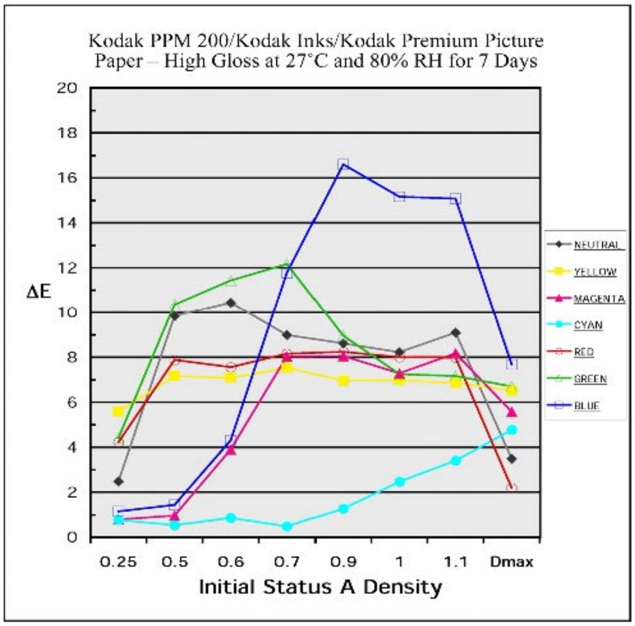

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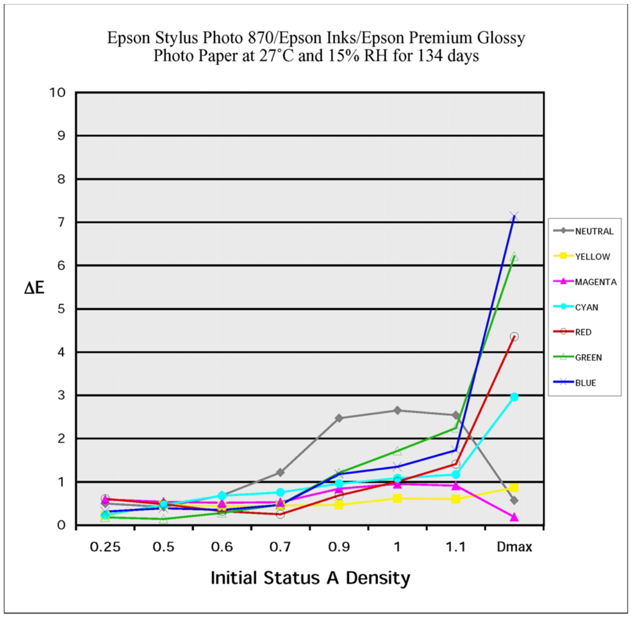

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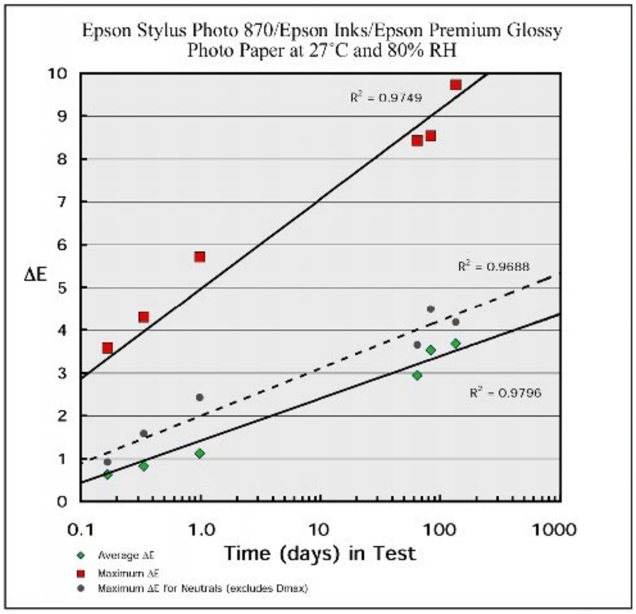

Figure 12.

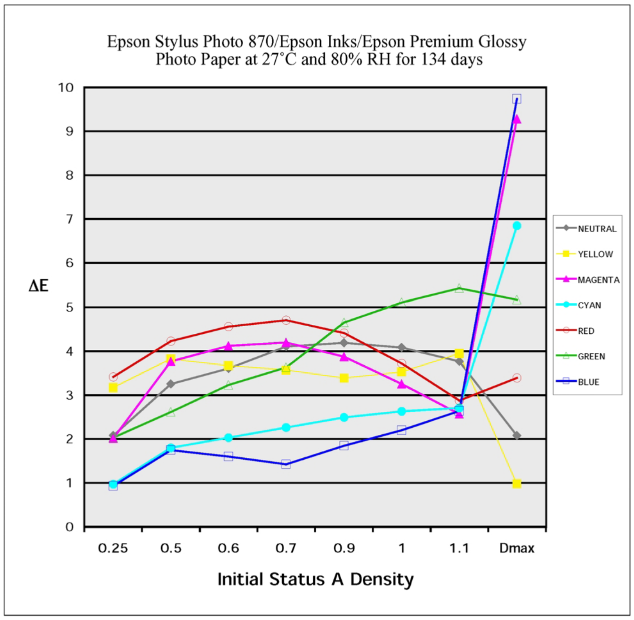

Figure 13.

the low to mid-density ΔE values that are inevitable in real world humidity conditions. This strategy only works, however, if the system is not vulnerable to further massive changes during real world excursions to high humidity levels. In Figure 12, a forward projection of the neutral data to 1000 days (2.7 years), and still further to the 9 to 10 years of predicted life on display, indicates that the Epson Premium Glossy Photo print would not exceed ΔE = 8 even if the print received continuous exposure to 80% RH. Although this dye-based system is not as resistant to humidity as the pigment-based system shown in Figure 1, its performance is probably satisfactory for amateur use. However, the strict short term ΔE requirements for color proofing systems would not be met.

Conclusions

The time interval between printing and assessing color balance and density is a critical determinant of how much further color change will be observed due to the logarithmic function of the colorant migration. The degree of color change slows down with time in a steady-state environment. Lower humidity levels generally retard the rate of change, but higher rates return when the prints are exposed to a higher humidity environment. More research is required to better understand the effects of cyclical environments.

The long term behavior of inkjet prints with respect to humidity-fastness requires a specific criterion for the time elapsed after printing in order for the results to have comparative meaning. Shorter elapsed time intervals are more demanding on the system but are better from the user perspective. Users do not want to wait to judge color balance and density. Small increases in relative humidity can have a significant impact on the rate of color change. Different colors can change at different rates, and intermixing of individual inks can enhance or retard the rate of color change that occurs when compared to the rate of the individual inks. The response of different printer/ink/media combinations can be dramatically different, although our tests to date support the general observation that pigmented ink sets have superior humidity resistance and lower short term color drift than do dye-based systems on the market today.

Printmakers who want to create more accurate color profiles of their printing system must be aware that with many current inkjet materials the short term color drift in the days or weeks after printing can reduce the accuracy of the profile if the measurement data does not account for it. Some systems are so sensitive to humidity effects that an accurate profile may not be possible.

Concern with humidity-fastness behavior is new to inkjet printing. It has not been a problem with traditional black-and-white and color photography or with digitally printed thermal dye transfer (“dyesub”) photographic prints_. Only since 1998 has it become a significant topic of discussion and research in the image permanence field.2-8 There has never been an ANSI or ISO test methods standard to evaluate this property. However, ANSI/ISO Subcommittee IT93 is currently developing a humidity fastness test for inclusion and the forthcoming ISO digital hardcopy image stability standard. Most consumers are not yet aware of the humidity-fastness issue, and tend to misattribute some of the color changes that they observe to light-fading or gas fading effects. Sorting out the various effects will be complicated when dealing with sensitive systems because the temperature and humidity levels that cause measurable changes are routinely encountered in real world conditions.

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