Humidity Diffusion of Dye-based IJ Prints

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Abstract

High humidity is one of the causes of print degradation particularly for prints in consumer homes. The study made on a typical set of ink-jet media and several commercial ink sets looks at ways to characterize the humidity sensitivity of such ink/media systems. In a first step, several factors influencing print degradation at high humidity were investigated. In a second step, a closer look was taken at the onset point where humidity degradation becomes objectionable. Sharpness and colour change metrics on the test image were compared to visual ranking of pictorial prints that had undergone the same humidity exposure. The Cielab DE difference on a checkerboard pattern exposed to varying levels of humidity is the most sensitive indicator to determine the threshold at which first image degradation occurs.

Introduction

There are various ways in which colorant diffusion affects prints. Ink-jet printing with aqueous inks can lead to colorant diffusion during the print process but also during later use of the print. The wicking of freshly printed ink into adjacent full colour areas is known as colour bleed and can be suppressed with adapted ink formulations. Users are advised to carefully dry their prints before they stack them as stacking prints before they are fully dried can lead to serious diffusion of colorant and of transfer to the overlying sheet. During the drying phase of ink on paper, a colour shift occurs while colorants spread laterally and vertically and solvents and water evaporate. This process is known as short-term colour drift or shift and is to be considered in print profiling and proofing, which are often done shortly after printing. The following investigation relates to fully dried prints and their degradation in high humidity environments. This process is the most relevant to the long-term storage of prints. The ISO committee TC-42, WG5 has been active for years to develop a test for humidity fastness and has done a lot of the work which was the start point for investigation below.

While in most other forms of image degradation for example by light or ozone, the colorant will undergo chemical degradation visible as colour loss on the printed image, high humidity induces dye diffusion, which is generally visible as an increase in density , a colour shift and a loss of sharpness. The colour changes on dot-printed patches do not correlate well with psychophysical studies on prints degraded by high humidity [1]. Some research groups have used cross hatch patterns of high density lines on white background [2] others full colour lines on various backgrounds [3] or checkerboard patterns [4] as test targets for humidity fastness. The selection of failure criteria on such test images is different from those developed for other permanence tests [5]. The loss of sharpness is often the most objectionable change in prints subject to high humidity. Line spread has been used to characterize such prints [3]. However, measuring line spread on large sample sets is not convenient and relating it to perceived image degradation is not obvious. A density or CieLab change on a cross-hatch or checkerboard pattern has been used instead [2,4]

The aim of the investigation was not to develop a system to rank or describe prints degraded by high humidity, but to rank the humidity performance of IJ print systems. This approach allows to limit the evaluation to the point at which first changes in sharpness and colour change become visible.

Experimental set-up

The humidity study was done on a sample set of proprietary ink-jet papers, one with a polymer layer (DTP), the others with nanoporous layers on RC base. The layer of media DN1 is based on a modified- alumina dispersion, media DN3, DN4, and DN7 are based on surface-modified silica nano particles. The media layer formulations were chosen so as to represent a wide range of photo-quality commercial ink-jet papers.

Four printers with the standard OEM inks were used to make the test prints with the manufacturers recommended settings for the media type. Other authors have looked at the effect of drying and pre-conditioning on humidity fastness and have found them to be of minor importance [6,7, 8]. As colour shift generally ceases [9] after 24 hours, prints were dried in ambient conditions for 24 hours and measured before they were submitted to the humidity chamber for 2 weeks. For the 4 weeks test, the same prints were submitted for a second exposure.

Table of Experimental conditions

Test set/conditions 1: T (target)=23°+/- 3° T (target)=30°+/- 1°	4 printers, 4 nanoporous, one polymer media @ 20%, 73%,85% @ 80%,85%,90% 2 and 4 weeks exposure
Test set/conditions 2 T (target)=25°+/- 1°	2 printers, 4 nanoporous media @ 20%, 60%,70%,80%,85% 2 weeks exposure

The test print pattern was the Checkerboard-Simple version described in [6]. It consists of 92 colour patches and Dmin and Dmax. 36 patches are dot-printed patches of primary and secondary colours in low, medium and high density. 56 of the patches are checkerboard patterned patches as described in [4] with 72 dpi squares-per-inches line frequency in each patch of high density squares on a white or low density background. It is very important that many colour combinations are present in the checkerboard patterned patches as dye migration is influenced by the presence of other dyes and the ink vehicles [3, 8].

Two pictorial images chosen to show the effect of sharpness and skin tone (Habor and 3 Women from [6]) were used in the visual ranking test. Those pictorial images were subject to the same conditions as the test pattern prints.

The incubation chambers were a Weiss Technik or a Climacell oven, which regulate the temperatures to +/- 1 ° and the humidity to +/- 2% of the target value. The chamber exposure was without light and the ozone level was below 5ppb.

The patches were measured with a Gretag/Macbeth ICColour in L*a*b* (D65, 2° observer, no UV filter, white backing). DE is defined as

$$DE = SQRT[(L2-L1)^2 + (a2-a1)^2 + (b2-b1)^2] \quad (1)$$

whereby L1,a1 and b1 are the L*a*b* values of the unexposed sample patch and L2,a2 and b2 are the L*a*b* values of the exposed sample patch. Average DE (AVDE) is the sum of all the DE of the exposed patches on a test image minus its unexposed reference patches, divided by the number of patches. AVDE has been found to correlate well with psychophysical studies [6]. MAXDE is the sum the worst 10% DE of a sample pair.

Line spread and edge measurements were done with QEA's PIAS-II equipment.

Results

Results of the experiments under test conditions 1

At temperatures close to room temperature and 2-4 weeks exposures, no change as reported in [11] was found in any of the systems at the low humidity condition of 20%.

Prints tested at 85% relative humidity (r.h.) and at either T= 23° or T=30° allowed to estimate the sensitivity of the test set to temperature changes close to ambient. The results at the two temperatures were the same within our experimental error. This agrees with the findings of others that in a small temperature range the humidity fastness test is not sensitive to temperature changes.

Figure 1 shows the effect of test duration. Increasing the humidity exposure from 2 weeks to 4 weeks does not increase AVDE considerably.

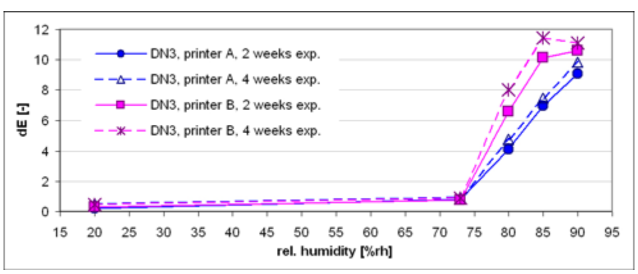

***Figure 1**. AVDE as a function of relative humidity for a nanoporous layer printed with a dye based ink @ 2 weeks and 4 weeks of exposure.*

Unlike other processes of fading that will lead to increased degradation of the colorant if the exposure continues, dye diffusion approaches a plateau [11]. Once the dye has migrated to evenly cover the lighter areas, no further migration occurs. The amount of migration depends on the test pattern. The checkerboard pattern with large dark areas was selected to promote such migration. Whereas according to [11] humidity fastness tests done on dot-printed patches reached a plateau after around 50-112 days, the checkerboard pattern reached the plateau in 14-28 days.

The effect of the layer composition is shown in fig 2.

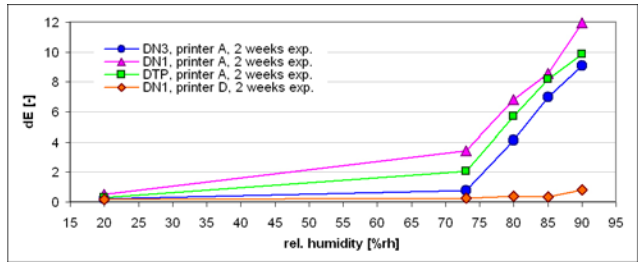

***Figure 2**. AVDE as a function of relative humidity for polymer and nanoporous layers printed with a dye based ink and a pigment print on media DN1,*

Polymer as well as nanoporous layers printed with dye–based inks exhibit very similar behavior when exposed to high humidity. At relative humidity below a certain threshold, the changes are generally small. In the majority of dye-based IJ print systems, there is a humidity level, at which the changes become much larger. The humidity at which the change of slope occurs is characteristic for a dye/layer combination and important for its use. Keeping prints at humidity levels higher than that threshold will degraded their image quality in a very short time, sometimes in a matter of days. The humidity insensitivity of pigment-based ink is shown in fig. 2 as well.

Results of the experiments under test conditions 2

The second test set was run at more humidity levels in the critical area of 60% r.h to 85% r.h in which the change of slope occurs. Prints were made on only two of the dye-based ink-jet printers on all of the nanoporous papers (DN1,DN3 ,DN4, DN7) used in the previous tests. The results of the 4 different nanoporous layers on RC paper printed with printer A and exposed to 4 humidity levels are shown in fig. 3.

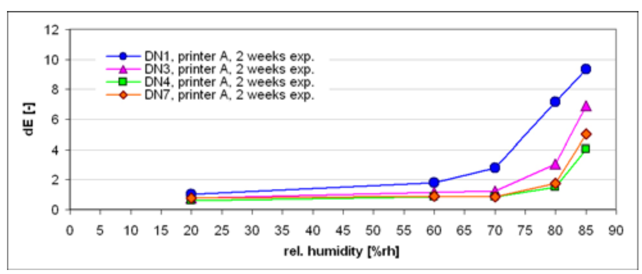

***Figure 3**. AVDE curves for test conditions 2, same printer, 4 different media,*

The curves show the slow increase of humidity diffusion in the r.h. range of 20% to 60% and the rather steep increase of AVDE above 75%-80% r.h. While in principal the four media/ink combinations exhibit a similar response to humidity, the threshold point is shifted and there are ink/layer specific differences due to the layer chemistry.

Fig. 4 shows the AVDE and MAXDE for two IJ media printed each on a different printer as a function of relative humidity. The graph demonstrates the difficulty to rank the humidity performance for IJ print systems.

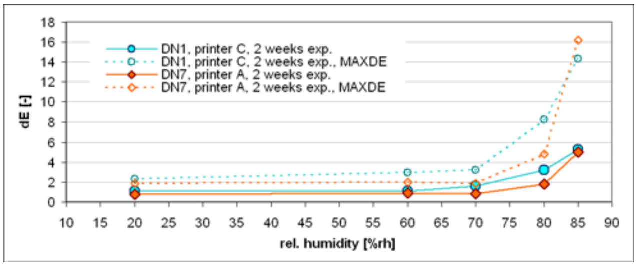

Figure 4*. AVDE and MAXDE for, two printers, two different media,.*

At 85% r.h., both print systems have the same AVDE of 5 and a MAXDE of 14.3 DN1/C vs. MAXDE 16.2 DN7/A. They should be ranked as having nearly identical humidity fastness. However, if the comparison is done at 80% r.h, the ranking is different. Print system DN1/C has an AVDE of 3.2 and print system DN7/A of 1.7. MAXDE at 80% r.h for systems DN1/C is 14 compared to 6 for system DN7/A. At this lower humidity, print system DN7/A exhibits appreciably better humidity fastness. A measurement of the AVDE at one humidity level does not describe overall humidity performance satisfactorily and could produce mis-ranking at other humidity levels.

Comparison of fastness metrics

An important property of a print system is the relative humidity at which a visible change occurs. This humidity level should not be surpassed even for a short period in handling or storing prints. The usual end point failure criteria [5] can not be applied to a mixed pattern such as the checkerboard patterned patches, but only to dot-printed patches. DE on a checkerboard patch is not a Cielab differences in colour. The measurement aperture of the spectral densitometers covers several dark and light squares on the checkered patches and averages over them. It is a measure for line spread as well as for colour. Good correlation of the checkerboard AVDE and MAXDE with line bleed was found in previous work [4,9]. The authors proposed a metric bases on colorimetric parameters. However, ranking of strongly diffused prints is very difficult. In fig. 5, the DE values for full colour on white checkerboard patches were correlated with line spread measurements on the same patches for one experiment with weak humidity diffusion and one experiment with strong humidity diffusion.

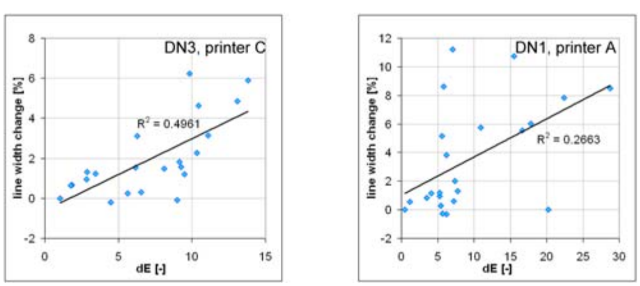

Figure 5*. DE correlated with line spread for the case of left) weak diffusion and right) significant humidity diffusion*

For weak diffusion, there is some correlation between DE and line spread, for strong diffusion it is less. The bad correlation is due to two factors. One factor is that if the dye fully covers the light area in-between two dark areas, line spread cannot be measured correctly. Measuring the humidity degradation with only a sharpness target would be fraught with the same problem. The two plots in fig 6 show an edge measured as reflection before and after strong exposure to humidity. The reflection in the light area does never reach the base value of the unexposed patch, the edge extends beyond the measured area.

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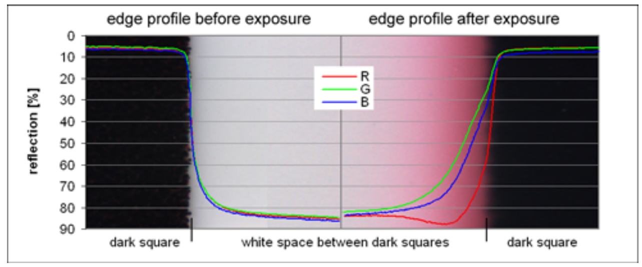

Figure 6 *edge profile of one dark checker board square and its light surroundings before and after exposure*

In fig. 6 the edge of the dark red area has not much changed nor has the visual sharpness, but the colour of the light patch has changed from white to pink. The spectral density measurement on the checkerboard characterizes such changes well as long as the colour of checkerboard square and background are sufficiently different. If they are of similar lightness, migration of the dye into the adjacent area does not cause a significant shift in DE. This is the second factor for low correlation between lien spread and DE Fig 7 illustrates the two cause for low correlation of line spread with DE.

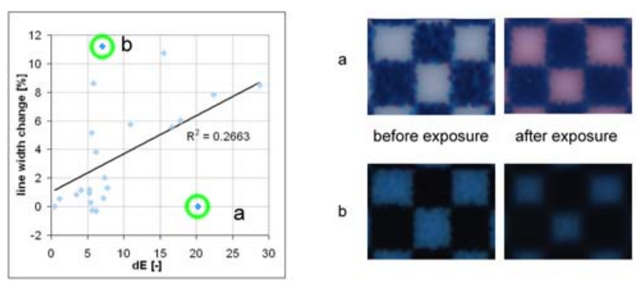

Figure 7 *correlation of measured line spread with DE for two colour combinations a) full colour on white, b) blue on black*

While AVDE of the test image has been found to correlate well to psychophysically rankings of typical images [6] that were exposed to high humidity, there was some concern that critical colours may not be considered enough. In colour faded images, the change in skin tone or grey is particularly objectionable and needs tighter failure criteria. To determine if an additional criteria was necessary such as a change in neutrals or skin tones, we exposed two pictorial prints from [6] and correlated their observed degradation to the measured test pattern changes. The ranking from 1-5 (1=no change, 2= perceptible change, 3=visible change affecting the image, 4=significant change and unacceptable image, 5= fully degraded image) was done in a small duo-stimulus comparison (2 experts) on the full set of prints made under test condition 1.

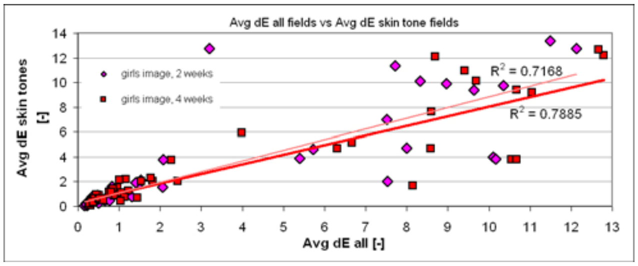

Figure8, *Correlation of AVDE skin tone and AVDE all colours*

Surprisingly, the humidity fastness ranking of this skin tone pictorial image did not correlate better with the AVDE of only the skin tones of the test image than with the AVDE of all colour patches. As skin tone and light grey are very light colours that show less humidity diffusion than dark lines, the pictorial images failed in sharpness before they failed in neutral or skin colour change. Fig.8 shows the very good correlation of AVDE of only skin tones for weak diffusion with overall AVDE values below AVDE =7.

The comparison of the AVDE of the 36 dot-printed patches with the 56 checkerboard patches on several of the print systems confirmed that the changes always occurred in the checkerboard part of the test image. AVDE on these images is 2-3 times higher than AVDE on the dot printed patches. The critical threshold of humidity fastness would best be determined on the checkerboard patches that do react very sensitively to the colour change caused by the line spread of the dark line into the light area. Line spread for dark lines on dark background are not well picked up by the AVDE metrics, however, they are also often not as critical in the visual perception.

Conclusion

The aim of study was not to develop a ranking of prints degraded by humidity as done in [10] but rather to determine the threshold level of humidity below which prints can be kept without long-term visible changes. Measuring changes at one humidity level can be problematic in ranking IJ ink/ media combinations for humidity fastness. It does not provide the information at which relative humidity the first visible changes occur.

Loss in sharpness and change in colour are suitable to serve as failure criteria, but both have their limitations. While measuring line spread on the checkerboard patches works well in the early phase of humidity diffusion, once the migrating dye has fully diffused through the light area, line spread can no longer be measured. The change of density over many checkerboard patches continues to be a good measure for the onset of dye diffusion, as long as the two checkerboard squares vary enough in lightness and colour. The checkerboard pattern based on [4, 6] shows changes caused by dye diffusion very sensitively. The AVDE values of the test image correlate quite well with a visual ranking of typical pictorial prints for moderately degraded prints. The checkerboard patterned patches alone could be the most critical target to determine the critical relative humidity threshold.

Acknowledgements

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Author Biography

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