The Light Fading of Dye Based Inkjet Images – A Multidimensional Issue

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Abstract

The fading of inkjet imagery has been the subject of many studies. This study explores the multidimensional nature of this issue using a single dye based inkjet ink set.

The aim is to show which variables are important to consider in the restoration of dye based inkjet images. As such images make their way into museum collections the variables influencing the fading process become important when preserving the cultural heritage. This study also identifies where inkjet media and ink technology is not yet up to the task and illustrate the archival properties, colour science and image physics of such imagery.

The influence of media type, printed colour and ink load are the primary variables explored. The correlation of the fading characteristics with ink coverage and penetration are also included.

The effect of light fading on image noise is also considered and a comparison of the characteristics of light and gas fading is made.

Whilst this study focuses on one ink set as an example a diverse set of media has been examined in order to illustrate the wide range of results that can be achieved. This illustrates the importance of the characteristics of the inkjet media in both the fading characteristics and any restoration process envisaged. An equivalent study with a different ink set would clearly give different results.

Introduction

In this study, the light fading characteristics of four very different media, printed with a common inkset, have been explored using a range of approaches and have been shown to be multidimensional in nature.

The simplest of the media used was a plain paper, i.e. a media without a surface coating of an ink receiving material, but with high wettability and absorbency. A cast coated paper was also chosen – the high level of surface microcracks on the surface of such a paper introduces some interesting effects. A glossy porous media was included; this had low wettability but was effective at fixing dyes close to the surface while draining away the dye solvents. Finally, a glossy swellable polymer product was used. This media was the most complex in design; consisting of several functional coated layers on a water impermeable substrate, with a polymer swelling mechanism for ink solvent take up. This media suffered from humidity related dye diffusion effects that occurred simultaneously with fading.

The differences in printing performance between these media, expressed as density versus ink load, were rationalized in terms of their surface characteristics.

The differences in fading behaviour between these media, arising from their different properties, were apparent in both densitometry and colorimetry measurements. It was also clear that for each of the four media, different colour dyes in the inkset used faded at different rates, and showed peak fading rates at different ink loads. A comparison of visual density and ink density showed that Status A density is not the best metric when making visual comparisons of fading.

The changes in colour occurring during fading were also investigated for the cyan and magenta dyes, and shown to be both complex and significant.

The effects of light fading on image noise were considered, and it was shown that the graininess of a print can change significantly during its lifetime as a result of ink dot size changes.

Finally, light fading of the porous media was compared with gas (dark) fading. In real environments, it is common for these to occur at the same time.

Experimental

Status A densitometry was developed to measure the density of traditional colour photographic materials. Red, green and blue colour filters are used to measure the optical densities of the 3 colorants. The characteristics of the filters evolved to match typical photographic colour dyes. However, ink jet colorants vary more in their characteristics, making this type of densitometry less pertinent.[1]

Much of the literature on permanence issues has used Status A densitometry to measure changes due to fading. However, a number of other metrics have been proposed.[1,2] In this work we have used both densitometry and colorimetry and have found that colorimetry provides the results that correlate best with visual appearance.

The media were printed with CMYKRGB step wedges at 10% ink level increments using the same printer settings for each media. Light fading was conducted in an Atlas Ci 4000 weatherometer using humidity cycling as described elsewhere.[3] The samples were measured before and after exposure for optical density (Status A and Visually Weighted) and colour using a Gretag Macbeth Spectrolino instrument. Image noise measurements were made on a QEA "Personal IAS" system.

Four different commercially available media were used to illustrate the effects. These were a plain paper, a cast coated paper, glossy swellable and glossy porous inkjet media.

In common with other dye ink sets[4] it was found that the fading was much less pronounced with the yellow ink compared to the cyan and magenta. Because cyan and magenta inks show more pronounced fading this paper concentrates on the characteristics of these inks to illustrate the various effects from light fading.

Ink – Media Interaction

It is instructive to consider colour density as a function of printed ink load as it reveals a number of differences between these media. The results were very similar for the CMY inks and are illustrated in Figure 1 for the cyan ink. There are a number of points worthy of note.

1. The porous and cast coated papers produce the highest densities at the heaviest ink load. However, their curve shapes are very different, with the cast coated having a much lower contrast at higher ink levels.
2. This reduction in contrast is the most marked with the plain paper.
3. The porous and polymer products have very similar characteristics, the major difference being the lower contrast of polymer product.

The different curve shapes can be explained as follows. When the ink droplet lands on the surface of the media it spreads across the surface, and the solvents penetrate down into the bulk of the media,[5] leaving the colour at the surface. This spreading process is governed by the wettability of the media by the ink.[6] This results in ink spots that have sizes and covering powers that are media dependent, as illustrated in Figure 2. (The spots on the porous media are not shown, but resemble closely those on the polymer media).

Measurements of the dynamic contact angle of a drop of water on the surface of each media were made to illustrate differences in wettability between the media (Figure 3).

Plain paper shows a rapidly decreasing contact angle, indicative of extensive spreading – this effect is seen to a lesser degree on the cast coated media. On the porous media, the droplet spreads slightly initially and then the contact angle remains stable. The polymer product shows the least spreading of all.

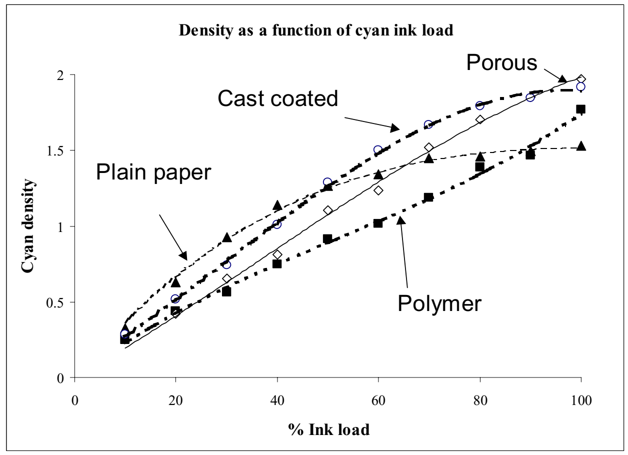

Figure 1. Density vs. cyan ink load

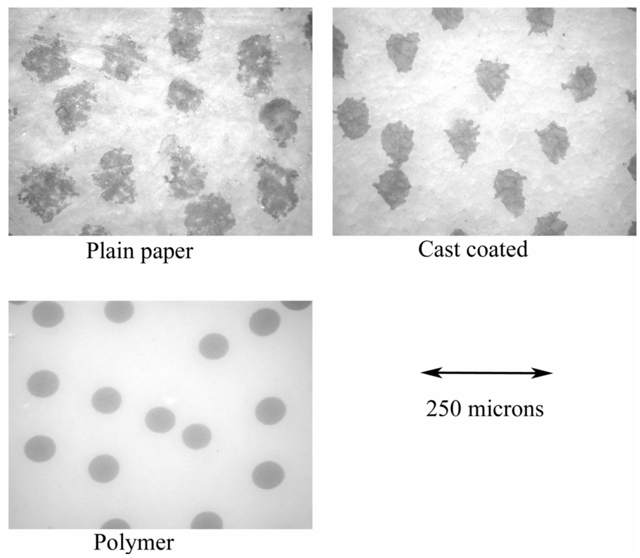

Figure 2. Cyan ink spots at 10% ink load

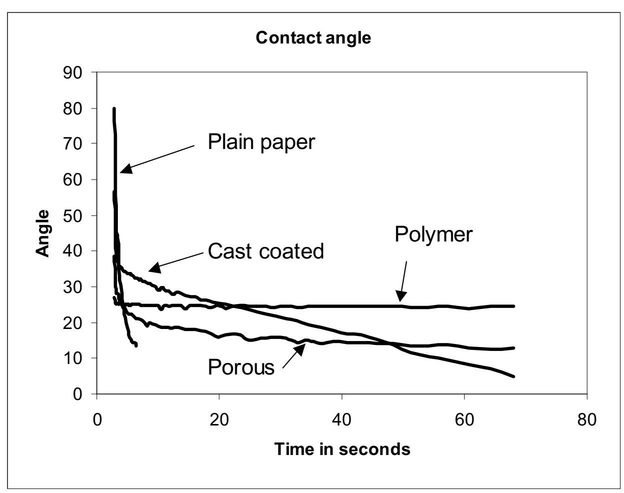

Figure 3. Contact angle

These differences in wetting behaviour go some way to explain the curve shapes in Figure 1. The large ink spreading on the plain paper increases the covering power at low ink loads, causing a greater density than the other media. Conversely, the lower dot gain of the polymer product leaves more space between ink spots, leading to a lower density for a fixed ink load.

The differences in wettability between media are also in some part due to the physical nature of the surface, as illustrated in the SEM pictures in Figure 4.

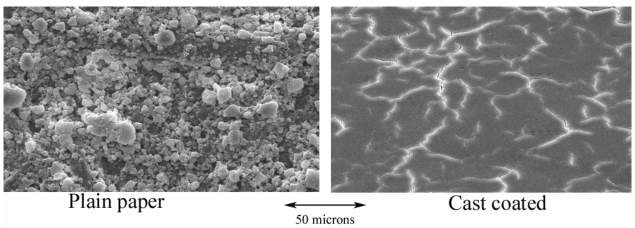

Figure 4. SEM pictures of the paper surface

Figure 4 shows the comparatively rough surface of the plain paper. This accounts for the asymmetric, diffuse spots on this media. On this scale the polymer and porous media are flat so these tend to give more symmetrical ink spots, as illustrated in Figure 2.

We can expect this spatial distribution of ink not only to affect the densitometry of the printed media but the light fastness too. This is because it influences the surface area available to catch the light.[7]

The Various Effects of Fading

In this work most of the fading results are presented as graphs of fading as a function of initial (unfaded) density. This has been found to be a useful tool to reveal the differences between media. Polynomial statistics were fitted to the fade data using the LINEST facility in Microsoft Excel. In most cases second order statistics were found to provide a good fit to the data. The resultant statistics were also useful in revealing the ink level at which peak fading occurred. This ink level showed a very low variability with indoor light exposure time. This is because fading was found to be a function of ink coverage, in agreement with some earlier published work[7].

Density Reduction

Figure 5 shows a comparison of 2 media at 24 hours Atlas exposure time.
The following points should be noted.

1. The relative fading of cyan and magenta inks is media dependent. The magenta ink fades more on the plain paper but the cyan ink fades more on the porous media. The cyan ink also faded more on the cast coated and polymer media.
2. The cyan ink results show that the density at which peak fading occurs changes with media type.

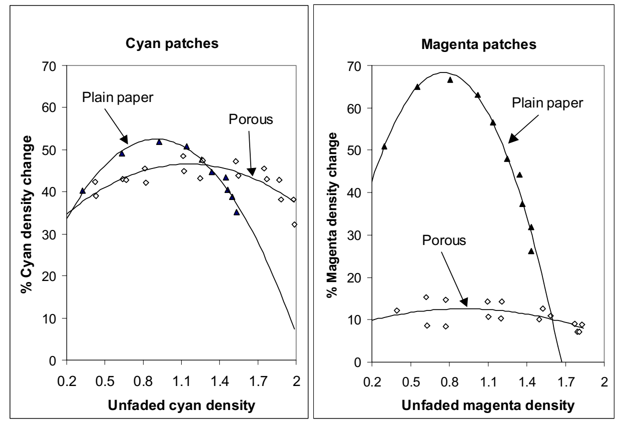

Figure 5. Ink density fading

The form of presentation of Figure 5 can hide an interesting fact. The polymer media magenta areas showed *progression* in this test, *accumulating* magenta density. This can be seen visually with the cyan patches looking faded but the magenta deepening somewhat. This effect also occurs with outdoor light exposure and is attributed to humidity related dye diffusion effects reported elsewhere.[4] The humidity causes the ink to migrate, increasing dot size and therefore ink coverage. This tends to *increase* density, mitigating somewhat the effects from light fading.

Light fastness endpoints are typically calculated at fixed ink densities.[8] However, over a spread of media the visual densities resulting from a fixed ink density can vary markedly, as illustrated in Figure 6. This illustration is for the cyan ink – the plot for magenta is very similar.

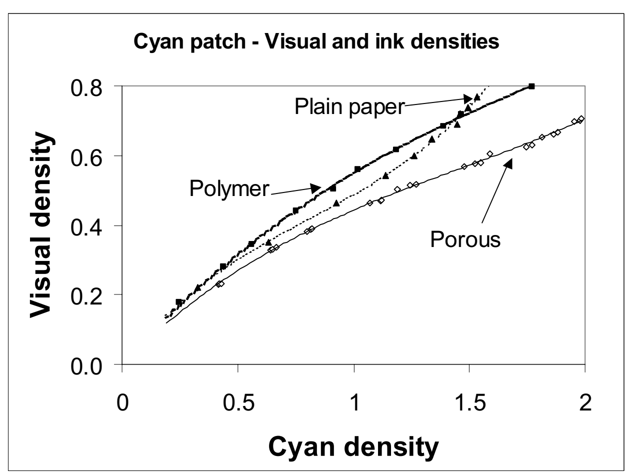

Figure 6. Visual vs. ink density

This disparity is the reason for the differences in colour gamut seen with different printed media – the same ink levels result in slightly different colours. However, this does mean that Status A density is not the best metric when making visual comparisons of different media for fading. For this reason visual density has been used for the rest of this work. As expected, this gives a better correlation with the visual perception of fading.

Changes in Delta E space

The relative merits of using densitometry or colorimetry for permanence investigations have been covered elsewhere.[9]

Figure 7 shows a comparison of 2 media, again at 24 hours Atlas exposure time. This time the changes are illustrated in Delta E space.

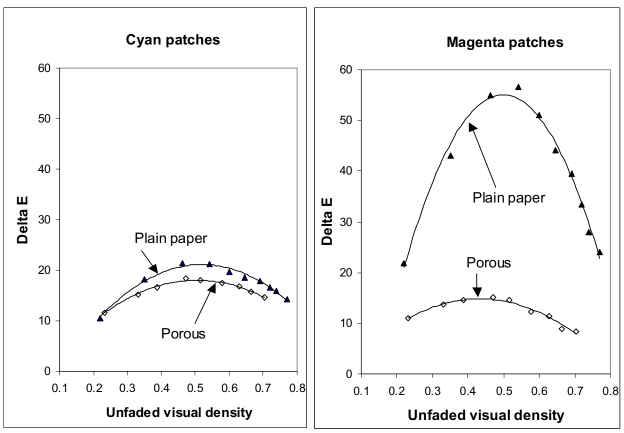

Figure 7. Ink fading in Delta E space – cyan and magenta inks

This form of presentation reflects visual inspection more accurately. The magenta ink fading is much more apparent visually for the plain paper but the cyan fade is slightly more apparent on the porous media. It should be noted that the relative fading in Delta E terms reveals more media dependence. The cast coated media shows greater magenta fade whilst the polymer media shows greater fade in the cyan. The effect on the polymer media is further complicated by the humidity effects described above.

Figure 8 illustrates the fading curves for RGB patches containing mixtures of the CMY inks. This more complex situation once more serves to illustrate the differences between media. In this instance all 4 media exhibit different characteristics! One of the causes of this may well be the differing extent of catalytic fading.[7]

The differences between inks are further illustrated by the *rates* of fade. This is shown in Figure 9 for the visual density corresponding to the peak fading. The issue is illustrated using the cast-coated paper as an example. With the exception of polymer (humidity bleed) the other media perform in a very similar fashion.

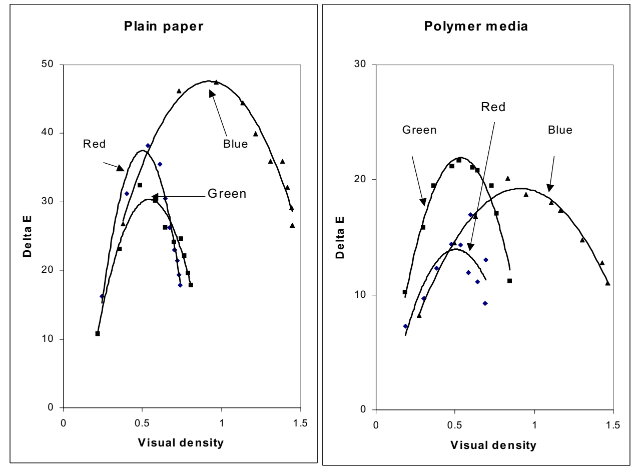

Figure 8. Ink density in Delta E space – RGB patches

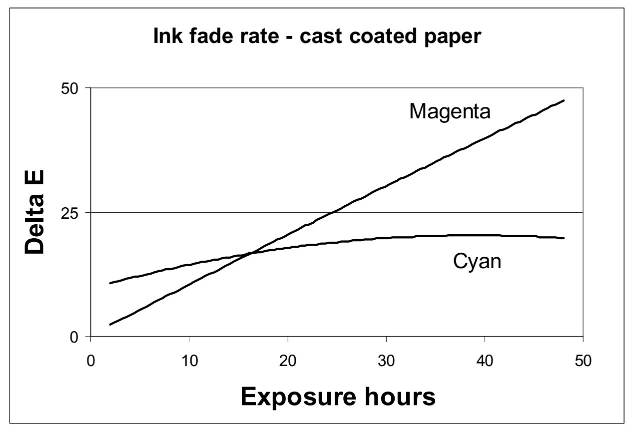

Figure 9. Rates of ink fade

It can be seen that the kinetics of the fading are very different for the 2 inks illustrated. The cyan initially changes very rapidly at very low exposures but then changes at a much more leisurely rate. The magenta ink on the other hand exhibits almost linear changes but on average with much more rapidity.

Image Colour

Presentation in terms of Delta E is an improvement on Delta D but once again does not tell the whole story. It fails to differentiate between *depth* and *changes* in colour. Figures 10 and 11 illustrate that substantial colour changes can take place on light exposure that in some cases are a function of ink load.

In figure 10 the lines join points of ink load 10-100%, increasing left to right. Each line reflects increasing exposure resulting in a trend to more positive b* values.

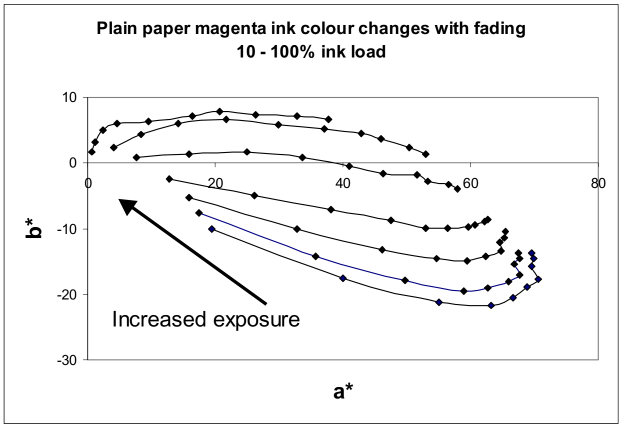

Figure 10. Lines of equal exposure – magenta ink

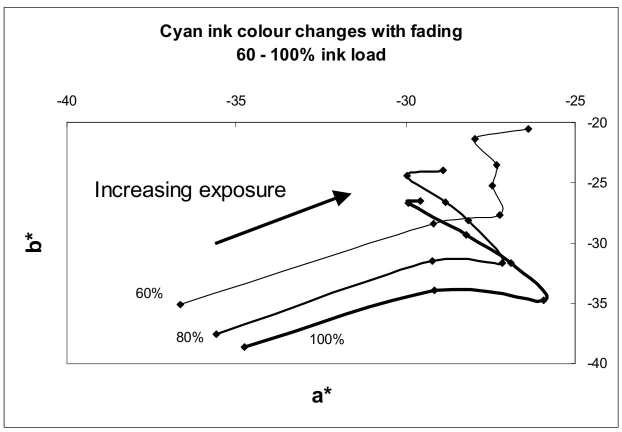

Figure 11. Lines of equal ink load – cyan ink

In Figure 11 the lines join points of equal ink load from 60-100% and increasing exposure. It illustrates complex colour changes with this ink.

Image Noise

As illustrated in figure 2 an ink jet print is made up of a complex array of ink dots. In this respect it resembles traditional photographic media. As a result, the printed image exhibits noise in much the same way as a conventional photograph. This can be seen in the form of mottle or graininess, dependent on the portion of the noise power spectrum considered.[10] The noise power spectrum will be a complex function of the parameters covered in "Ink – Media Interaction" above and will change when the image is altered due to exposure to light (and/or humidity). This is because the light induced fading does not take place in a uniform manner across the inked areas.

This is illustrated in Figure 12 for cyan ink on the porous media. The corresponding figures for the magenta ink are very similar.

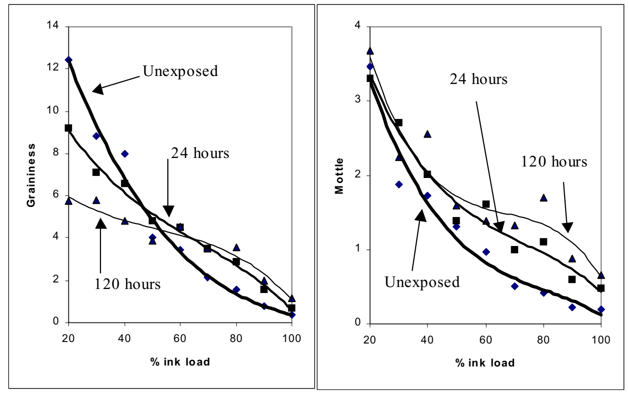

Figure 12. Cyan noise changes on porous media

It can be seen from Figure 12 that the effect of light fading in this case is to decrease the perceived graininess at low ink loads (low density areas) but increase the perceived graininess at high ink loads (high density areas). The lower spatial frequency mottle also increases at higher ink loads.

At low ink loads the image consists of discrete dots, progressing to overlapping dots at higher densities or mixed colours. The shapes of the dots are media dependent and in the case of plain and cast coated papers the dots are irregular. The key point is that the density profiles are not sharp. As a result, the dots tend to *decrease* in size on light fading. Polymer media tends to be an exception to this, presumably because the effects of humidity tend to balance this effect.[7]

One result of this decrease in dot size is a change in the noise power spectrum. In visual terms this means that the perceived graininess and mottle of the image changes as a function of printed density and light exposure time.

The cracked surface structure of the cast coated paper shown in Figure 4 provides an unusual structure to the faded dots, illustrated in Figure 13.

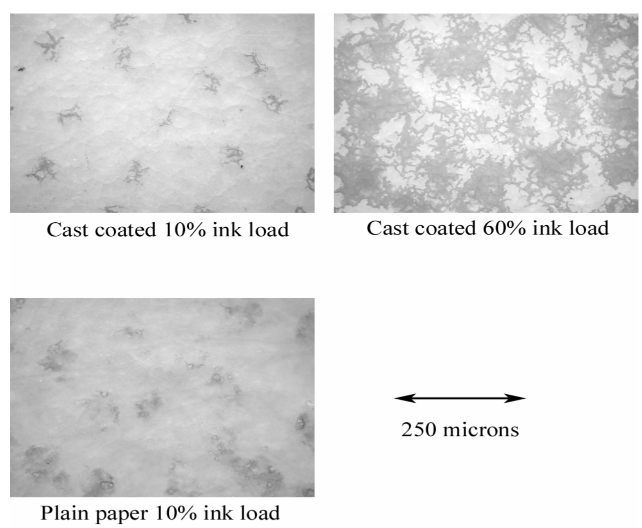

Figure 13. Cast coated and plain paper cyan faded areas

The cracks in the cast coated paper tend to accumulate ink and as a result tend to be higher in density. After light fading the ink in the surrounding areas tends to fade away, leaving an image that is more filamentary than dot in nature. By way of contrast, the plain paper tends to fade to a much more random image.

A comparison of Gas and Light Fading

It is interesting to compare the characteristics of light fading with the effects of atmospheric pollution, commonly known as gas fading.[9] Porous media are known to be more susceptible to gas fading and the characteristics are illustrated in Figure 14.

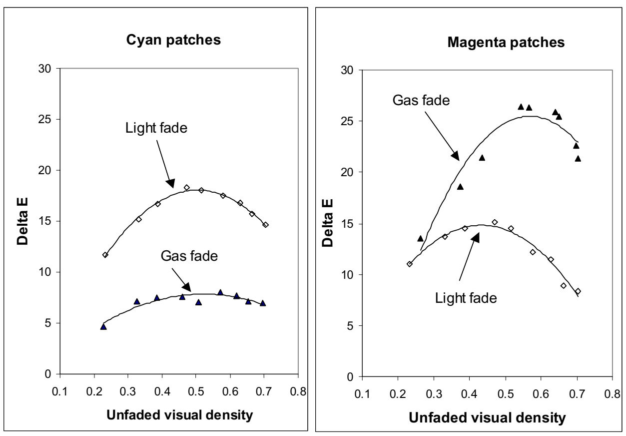

Figure 14. Gas and light fading comparison on porous media

The porous light fade figures are taken from Figure 7 but in this case are compared with a 28 day fade from a dark cabinet with forced air feed[9] to promote gas fade. It can be seen that for the cyan ink the gas fade curve shape is very similar to that of the light fade. However, this is not the case for the magenta ink. It can also be seen that the relative sensitivities of the inks to light and gas fade are reversed.

Gas fading is an important consideration when considering light fade of images displayed without a covering layer such as a sheet of glass. In this case fading can be a very complex mixture of the 2 effects.

Conclusion

It has been shown that the fading characteristics of these images are a highly complex issue. Issues such as the printed spot size and shape are shown to be important and linked to the wettability of the media and the surface nature. The media type and printed colour are also important drivers. The use of visually weighted densitometry and colorimetry has been found to be useful.

The rates of fade of the different coloured inks in this inkset have been shown to be different. The colour of the image has been shown to vary in a complex manner on fading. Image noise has also been shown to vary with light fading.

Finally, the characteristics of gas fading have been shown to be somewhat different to light fading.

References

1. E. Baumann, M. Fryberg, R. Hofmann, M. Meissner, *"Colorimetry vs. Densitometry in the Selection of Ink-jet Colorants"*, Proc. PICS, 107 – 111 (1999)
2. H. Ishizuka, Y. Seoka, Y. Shibahara, E. Sakai, *"End Point Criteria for Evaluating Image Stability of Digital prints"*, IS&T's NIP19, 411 – 414 (2003)
3. M. Meissner, E. Baumann, R. Hofmann, "*The Role of Humidity Cycling in Accelerated Light Fastness Tests", IS&T's DPP2003, 203–204* (2003)
4. E. Baumann, R. Hofmann, *"The Characterisation of Humidity sensitivity of Ink-jet Prints",* IS&T's NIP19, 402 – 405 (2003)
5. H. P. Le, *"Progress and Trends in Ink-jet Printing Technology"*, J. Imaging Science and Technology 42(1), 49-62 (1998)
6. P. Emmel, R. D. Hersch, *"Modeling Ink Spreading for Color Prediction"*, J. Imaging Science and Technology 46(3), 237-246 (2002)
7. S. Schüttel, R. Hofmann, *"The Influence of Diluted Inks and Drying on the Lightfastness of Dye Based Ink-Jet Prints"* IS&T's NIP15, 120 – 123 (1999)
8. H. Wilhelm, "*How Long Will They Last? An Overview of the Light-Fading Stability of Inkjet Prints and Traditional Color Photographs*", IS&T's 12th International Symposium on Photofinishing Technology, 32 –37 (2002)
9. R. Hofmann, E. Baumann, R. Hagen, "*Density versus Colorimetry for Permanence Investigations"* IS&T's NIP17, 209 – 212 (2001)
10. J. C. Dainty, R. Shaw "*Image Science*" Academic Press (1974)

Biographies

Alan Hodgson has a BSc and PhD from the Department of Chemistry of the University of Manchester Institute of Science and Technology. He joined ILFORD Imaging in 1982 working in Image Physics R&D on optical instrumentation and testing methods. After a number of technical support and Sales & Marketing roles he is currently Manager of the Technical Services group in the UK, covering both traditional silver image and emerging ink jet technologies.

Amanda Jackson has a BSc from King's College, London and an MSc from the University of Hull. She joined Ilford in 1987 working on silver halide photographic emulsion research. After various research and product development roles she is currently a Research Associate and leads the Inkjet Media section in the Manufacturing Technology Group.