The Fading of Dye Based Inkjet Images – Colorimetric Issues

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Abstract

The fading of inkjet imagery has been the subject of many studies. This study follows on from one presented at the previous Archiving conference, expanding on the investigation of colorimetric changes during fading processes.

The aim of this study is to illustrate the important issues to consider in the restoration of dye based inkjet images. As such images make their way into museum collections these issues become important when preserving the cultural heritage. This study will also identify where inkjet media and ink technology is not yet up to the task and illustrate the archival properties and colour science 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.

Whilst this study picks on a single ink set as an example, two very different types of media have been studied in order to illustrate the wide range of results that can be achieved. This will emphasise the importance of the inkjet media in both the fading process and in any restoration envisaged.

The characteristics of the cyan, magenta and yellow in this ink set will be shown to be very different. The implications of these differences in the fading of these images will be explored. In addition to pure CMY colours, the effects on RGB combinations will also be considered.

Whilst this study concentrates on the light fading of a dye based ink set the results are compared and contrasted with gas fading and light fading of pigmented inks.

Introduction

In this study, the light and gas fading characteristics of two very different media, printed with a common ink set are explored. The ink set used, a four colour CMYK set, provided a simple model to illustrate the issues.

This study builds on earlier work that explored the light fading characteristics of this ink/media combination.[1,2] The commercially available media used can be described as follows.

1. A plain paper. This is a media without a surface coating of an ink receiving material, but with high wettability and absorbency.
2. A swellable polymer media. This consisted of several functional coated layers on a water impermeable substrate, with a polymer swelling mechanism for ink solvent take up.

In the first of this series of papers[1] it was shown that for this specimen ink set the rates of fade of the individual inks were significantly different. This ratio also depended on the printed media chosen. The first paper also illustrates some of the earlier work on the colour changes discussed here.

In the second paper[2] it was shown that the density changes on fading are in general quite a linear function of unfaded ink density at all but the highest density levels. In addition, gas fading tended to give a more linear response than light fade at these higher densities. The paper also illustrated that these inks are prone to the effect known as catalytic fading to light and preferential fading of cyan to atmospheric gases. Again, gas fading is shown to be a more simple system.

In the first of these papers it was also shown that in some cases there are complex colour changes accompanying light fading. The purpose of this work was to gain a greater understanding of the colour shifts that accompany light and gas fading and thus gain a greater understanding of the parameters that influence these. 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. The work may also have some implications for the setting of illustrative end-points.

Experimental Conditions

The media were printed with CMYKRGB step wedges at 10% ink level increments using the same printer settings for each media. The samples were measured before and after exposure using a Gretag Macbeth Spectrolino instrument.

The light fade results were achieved using a Xenon arc exposure filtered through window glass with humidity cycling as described elsewhere.[3] The gas fade results were achieved from a dark cabinet with forced air feed.[4]

Ideal Characteristics

In an ideal world inkjet images would not be vulnerable to light and gas fading. Whilst the technology has improved over time, inkjet imagery is still subject to these fade processes to some extent. If we take the realistic case and assume that these fading processes will occur then we can set some criteria for the behaviour of an ideal ink set as follows.

1. Consider first the fading of an individual C, M, Y or K ink at any ink load; fading should not produce any change in hue angle of the colorant. The faded image would then still accurately record the hue of the original.
2. Fading of an individual C, M, Y or K ink should be by some measure linear with ink load. The faded image would then still accurately record the tonal range of the original.
3. In the more practical example of areas that are printed with a mixture of CMYK inks the individual inks should fade at identical rates. If this were not the case then colour shifts would occur on fading due to the change in ratios of the remaining inks.
4. Again in areas consisting of a mixture of CMYK inks the rate of fade of individual inks should not be a function of the amount of another ink present. If this were not the case then the system would be classed as non-linear, complicating the issue significantly. A more detailed analysis of linear systems in imaging can be found elsewhere.[5]

Adherence to these criteria of an ideal system will make any restoration of a faded image easier to do and make it a more accurate representation of the original.

This paper illustrates issues with criteria 1 and 3. Criteria 2 and 4 were dealt with in a previous publication.[2]

Cyan Ink

Figure 1 illustrates a simple fading example of cyan ink on plain paper. It shows the colour of the printed area in CIE a*b* space for 3 different ink loads of 10, 20 and 40% (Status A density 0.3 to 1.1). Each of these ink loads was subjected to 0, 0.17, 0.33, 0.67, 1.33, 2 and 4 Mluxh light exposure to give the 7 points on each line in Figure 1. Light exposure causes the dyes to fade thus decreasing colour saturation and causing a consequential reduction in both a* and b* values, as plotted in Figure 1. For each of the three lines in Figure 1 exposure therefore increases from bottom left to top right as the samples fade towards a white point.

It can be seen that this simple example fulfils one of the ideal characteristics listed above. Fading does not produce any large changes in hue angle - the data points do not deviate substantially from a hypothetical straight line joining the data and a white point near the origin. Indeed, a faded sample of a higher ink load has a very similar colour to an unfaded sample of a lower ink load.

Figure 2 illustrates a more complex situation with the cyan ink, this time printed onto the polymer media.

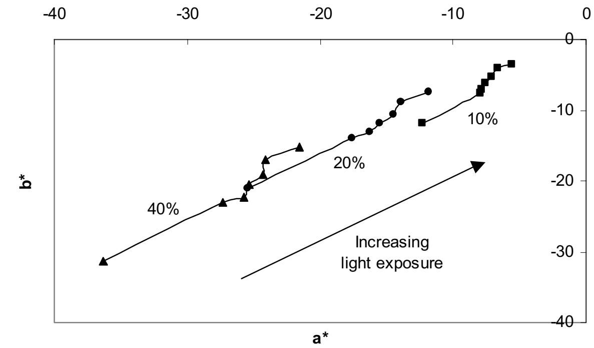

Figure 1. Light fading of cyan ink on plain paper

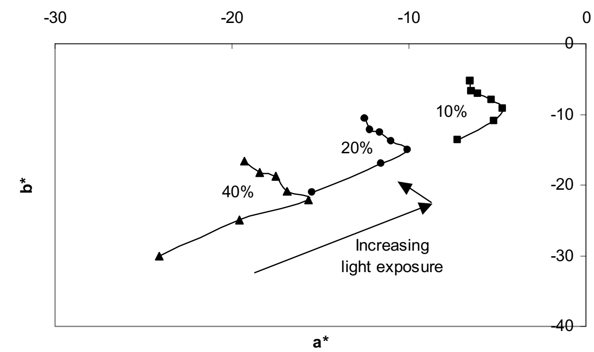

Figure 2. Light fading of cyan ink on polymer media

In this case the initial fade is very similar to the simple fade shown in Figure 1 for plain paper. However, on further fading the colour of the samples takes an abrupt turn towards more negative a* values, acquiring a greener hue. Reference back to Figure 1 reveals some slight indication of a similar trend with plain paper, but of much lower magnitude.

There are a number of possible causes for this effect.

1. Some inks consist of a mixture of colorants, designed to balance colour saturation and permanence. These may have different hues and fade at different rates. The result of this would be a colour shift on fading.
2. Differences in aggregation behaviour of the dyes in different media. In addition to aggregation changing the light fastness behaviour of the dyes on accelerated testing[6] it will also change the hue. As the printed area is subjected to fading the concentration of the colorant will decrease. This will in turn affect the degree of aggregation[7] and therefore the resultant hue.
3. Polymer media is susceptible to ink bleed due to a combination of temperature and humidity.[8] This ink spreading effect will not only change the aggregation behaviour (see above) but could lead to a separation of colorants by chromatography in the media.

A further clue to the cause is revealed in Figure 3. This is the same chart as Figure 1 but with some higher ink loads now included. Here it can be seen that at higher ink loads the hue of the unfaded ink is displaced to more negative b* values – it is bluer. After some initial fading this blueness disappears and the fading continues in a fashion very similar to the lower ink loads.

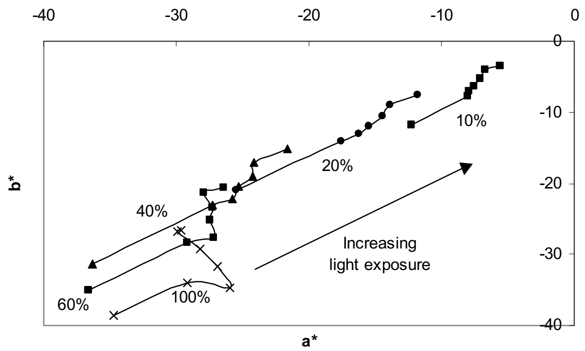

Figure 3. Light fading of cyan ink on plain paper at high ink loads

Plain paper therefore shows the same effect as polymer media, except that the onset of this effect occurs at much higher ink loads. This suggests that it is a concentration issue influencing aggregation.

Consideration of some photomicrographs reinforces this theory. Figure 4 shows a picture of the cyan ink dots at low ink load on the 2 media. It can be seen that the dots on the polymer media are somewhat smaller, leading to a higher dye concentration and therefore increased aggregation.

This situation also applies to the distribution of the ink into the depth of the media, as illustrated in Figure 5. This shows that in the case of the polymer media the dyes are confined to a much thinner layer, again increasing the concentration and therefore the aggregation.

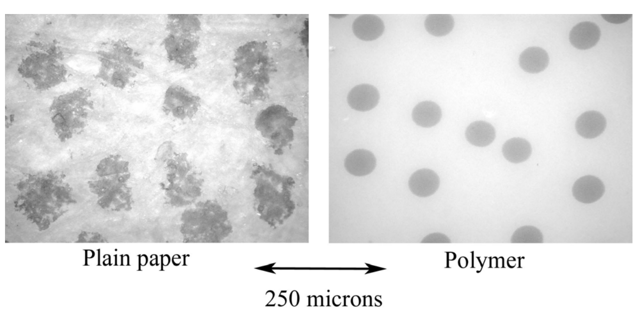

Figure 4. Cyan ink spots at 10% ink load

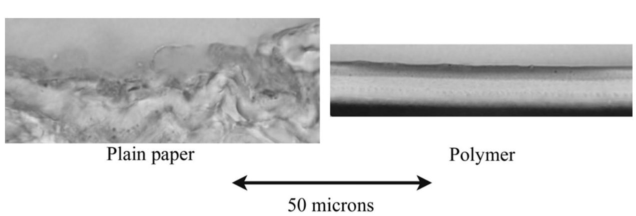

Figure 5. Cyan ink spot sections - plain paper and polymer media

At higher ink loads there is a substantial amount of overlap of the individual ink spots on the surface of the media. However, this increase in ink load does not in general result in the ink penetrating deeper into the media as illustrated in Figure 6.

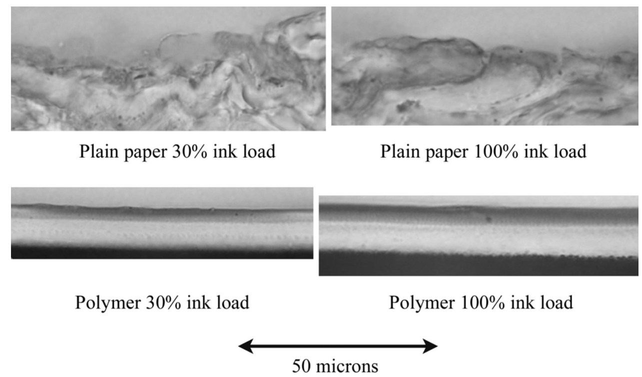

Figure 6. Cyan ink spot sections as a function of ink load

It will be seen that apart from some irreversible swelling of the polymer media the thickness of the dye layer in both cases remains substantially unchanged. These effects will increase the concentration of the ink in the media and should therefore drive further dye aggregation as ink load increases.

These pictures give a good explanation of the behaviour of these 2 media. In the case of the plain paper ink spreading on drying takes place,[1] distributing the colorant in area (Figure 4) and in depth (Figure 5). At higher ink loads (Figure 3 suggests 40-60%) the dye reaches a concentration where significant aggregation begins to take place and the unfaded spots change hue. Under light exposure, the colorant begins to fade and the concentration reduces. Aggregation therefore decreases and the colorant resumes its previous hue.

Further evidence for changes in aggregation in this plain paper comes from gas fade results. It is known that dye aggregation level is one of the variables that influence gas fading.[9] At the ink load where aggregation becomes significant we should therefore see a change in gas fading behaviour. This is indeed the case as illustrated by Figure 7, following the method of presentation in the previous work.[2]

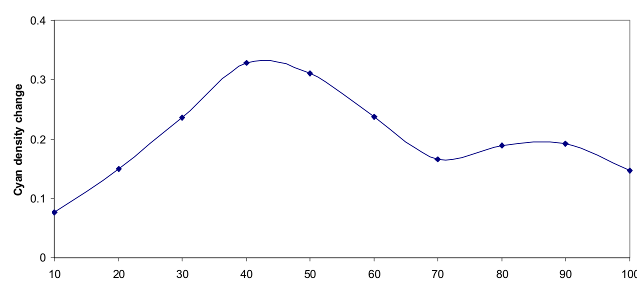

Figure 7. Gas fading of cyan ink on plain paper

In the case of the polymer media the thinner layer of colorant results in higher concentrations of colorants. This, together with the different chemical environment of the polymer layer induces aggregation at all ink loads. As a result, the polymer layer will exhibit the complex colour changes illustrated in Figure 2 at all ink loads.

Magenta Ink

Comparing Figure 1 and Figure 8 shows that the magenta ink fades in a very different fashion to the cyan. In this case the samples fade towards a hypothetical point that is a function of ink load and had a positive b* value. This means that the samples fade towards a yellow rather than a neutral shade as is the case with the cyan.

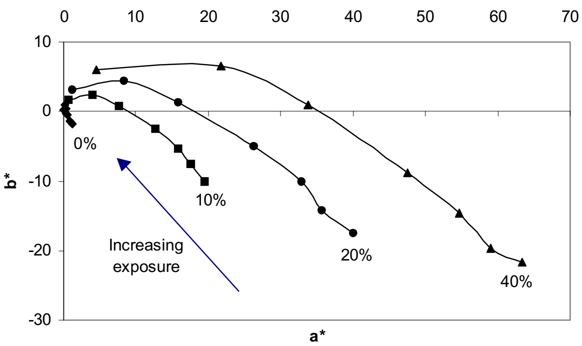

Figure 8. Light fading of magenta ink on plain paper

Figure 8 also includes the fading characteristics of the unprinted material, labeled as 0%. This material shows a small amount of change towards a point near to the origin.

It can also be seen that in this case a faded sample of a higher ink load shows a rather different colour to an unfaded sample of a lower ink load – there is a substantial shift towards the yellow.

Yellow Ink

As found in the previous study with this ink set[1], the rates of fade of the yellow ink are much lower. This fact becomes significant when we consider mixed colours.

Mixed Colours – RGB

In the sections above the relevant issues have been illustrated using printed patches of pure CMY inks. However, in "real" prints coloured areas use a mixture of inks that introduce their own complications.

The problem of unequal fading of the CMY components is the most obvious and the easiest to demonstrate. It has been shown previously with this ink set[1] and in many others documented in the literature that CMY inks within an ink set often fade at different rates. When mixtures of inks are used to produce colours other than CMY this will mean that the hue will change on fading. However, as illustrated below these hue changes can be highly media dependent.

The first example illustrated in Figure 9 is unusual in that this colour/media combination works quite well! The colour fades towards the neutral at all ink loads. There is also little indication of any of the complexities associated with aggregation.

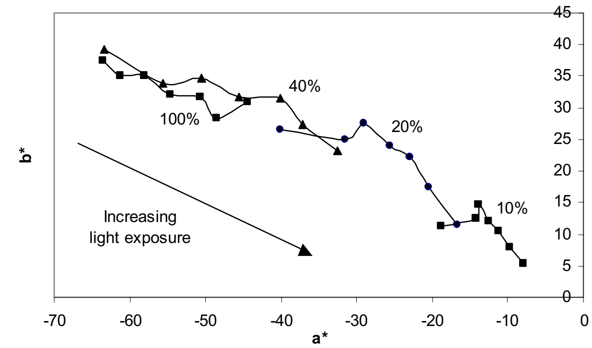

Figure 9. Light fading of green printing on plain paper

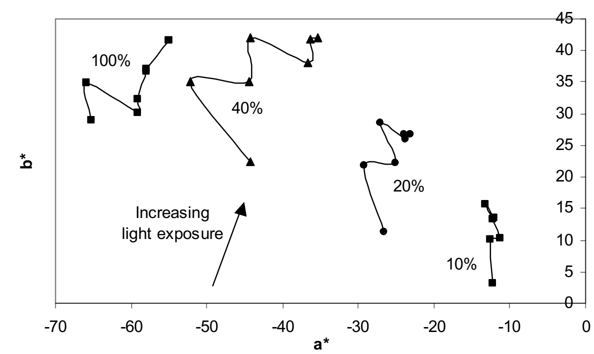

Figure 10. Light fading of green printing on polymer media

However, by way of contrast the same print on the polymer media produces a very different result.

In this case the print fades towards yellow instead of neutral.

In the case of blue areas there is the additional complication of catalytic fading, where the presence of one ink promotes the fading of another[2]. Unfortunately, this effect is also media dependent, as illustrated in Figure 11 and Figure 12.

Figure 11 shows the colour change on light fading of blue areas on plain paper. In this case light fading produces a shift in hue towards green – the area effectively loses magenta density more than cyan.

It is a very different story if the same combination is printed on the polymer media. As shown in Figure 12 light fading produces first a shift towards the red and then towards neutral.

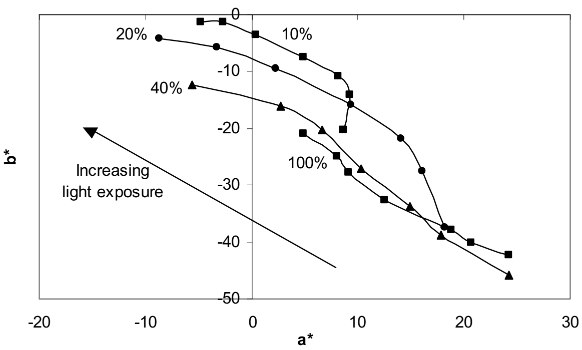

Figure 11. Light fading of blue printing on plain paper

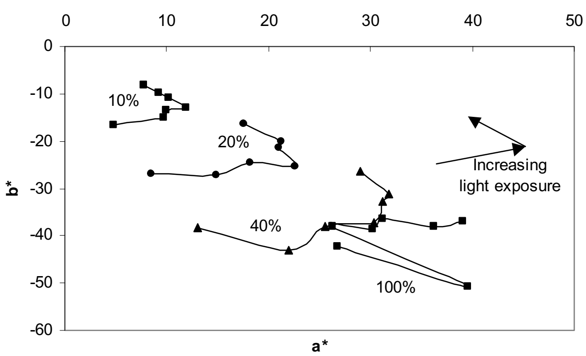

Figure 12. Light fading of blue printing on polymer media

Other Dye Systems

It should be noted that this is a simple 4 ink system, chosen to illustrate the issues in as simple a form as possible. Other dye ink systems that incorporate dilute (light) inks will have other issues, most notably around the aggregation behaviour.

Gas Fading

Whilst the light and gas fading characteristics of these ink and media combinations are known to be substantially different[2] there are also some similarities. Figure 13 shows the a*b* coordinates of a cyan swatch printed on plain paper at 10 different ink levels. The 2 points on each line correspond to the unfaded condition and a gas fade of 28 days as described elsewhere.[4] In all cases the unfaded case is the point with the most negative b* value.

Comparison with Figure 3 shows that this fading method again results in similar colour shifts that are dependent on ink loads. This is to be expected as gas fading too is dependent on aggregation – see above. However, the major difference to note between light (Figure 1) and gas (Figure 13) fading is that whilst light exposure at low ink levels produces fading towards neutral (near the origin on the graph) gas fading produces a significant yellowing of the printed area, a shift towards positive b* values.

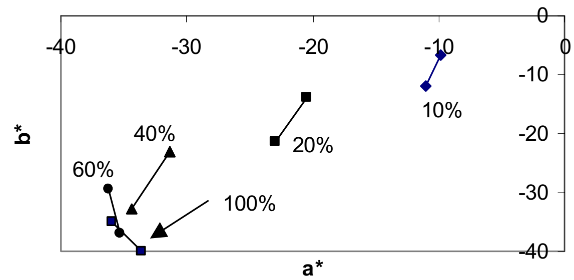

Figure 13. Gas fading of cyan ink on plain paper

Perceptual Issues

In the long-term conservation and restoration of works of art colour changes due to fading are of interest to conservators. There is however a further issue worthy of consideration. Are these changes acceptable and/or perceptible to an observer? Published work[10] shows that the scale of these colour changes are unacceptable. The work showed that colour changes greater than around 5 ΔE* units are would be deemed as unacceptable by most observers.

This issue also has implications for the setting of illustrative end-points for the effective life of inkjet prints. These are typically defined in terms of changes to Status A densitometry. 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, as ink jet colorants are more variable in their characteristics, and can show colour shifts of the type described above, the benefits of Status A densitometry look less clear.[1]

Pigmented Inks

Although pigmented inks are less prone to light and gas fading they are not immune from these effects. Also, as briefly illustrated below, they show similar colour effects to those illustrated above.

This is illustrated first for a cyan pigmented ink printed in a typical combination with a porous media. The presentation is the same as Figure 1, with light exposure increasing towards the origin of the chart. Some colour shifts can be seen to occur, on a similar scale to those in Figure 3.

There can also be issues with mixed colours where a mismatch of the fading rates of the individual inks can cause colour shifts on fading. This is illustrated in Figure 15, which illustrates the differences in light fading rates of a single set of CMY pigmented inks. It can be seen that in this case the yellow ink is much less stable then the cyan and magenta components.

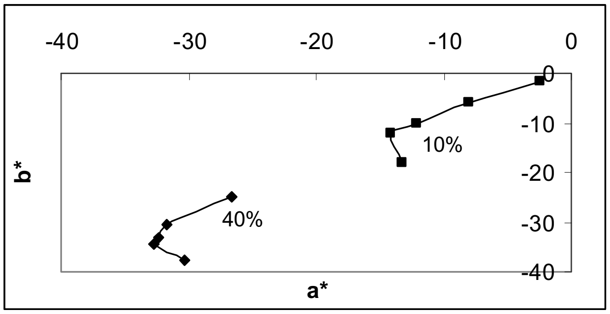

Figure 14. Light fading of a cyan pigmented ink

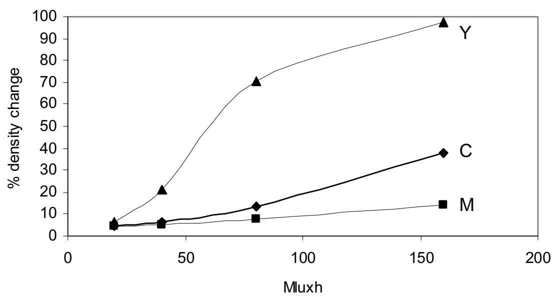

Figure 15. Light fading of a CMY pigmented ink set

Conclusions

This study illustrates some of the colorimetric changes that can occur during fading processes. These are important issues to consider in the restoration of dye based inkjet images. It has been shown that media type, printed colour and ink load are important variables and that results from one combination may not necessarily reflect the performance of another combination. Fading is shown to vary with ink coverage and penetration.

The colorimetric issues are complex with pure CMY colours, making the effects on other colours even more so.

Whilst this study concentrates on the light fading of a dye based ink set the results are compared and contrasted with gas fading and light fading of pigmented inks and similar issues are observed.

The complexity and magnitude of the colour shifts observed suggest that these should be considered in the setting of illustrative end points for effective print life.

Acknowledgements

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References

1. A. Hodgson and A. M. Jackson, “The Light Fading of Dye Based Inkjet Images – a Multidimensional Issue”, Proc. IS&T’s Archiving Conference, 43 – 48 (2004).
2. A. Hodgson and A. M. Jackson, “The Differences in Characteristics of Dye Based Inkjet Images subjected to Gas and Light Fading”, Proc. IS&T’s NIP20, 734 – 739 (2004).
3. M. Meissner, E. Baumann and R. Hofmann “The Role of Humidity Cycling in Accelerated Light Fastness Tests”, Proc. IS&T’s DPP2003, 203 – 204 (2003).
4. R. Hofmann, E. Baumann and R. Hagen “Density versus Colorimetry for Permanence Investigations”, Proc. IS&T’s NIP17, 209 – 212 (2001).
5. J. C. Dainty and R. Shaw “Image Science” Chapter 6. Academic Press ISBN 0-12-200850-2 (1974).
6. M. Oakland, D. E. Bugner, R. Levesque, and P. Artz “Arrhenius Testing under Controlled Atmospheres: Measurement of Dark Keeping Properties of Inkjet Photographic Prints”, Proc. IS&T’s NIP 17, 167 – 170 (2001).
7. See D. J. Shaw, “Introduction to colloid and surface chemistry” Chapter 4 ISBN 0-408-70021-1 for an explanation of the Law of Mass Action applied to aggregation.
8. E. Baumann and R. Hofmann, “The Characterisation of Humidity sensitivity of Ink-jet Prints”, Proc. IS&T’s NIP19, 402 – 405 (2003).
9. A. Hodgson “The Factors influencing the Dark Stability of Inkjet Images”, Institute of Physics conference on Preservation and Conservation Issues Relating to Digital Printing and Digital Photography”, 96 – 101 (2003). ISBN 0-7503-0991-1.
10. M. R. Pointer, G. C. Attridge and R. E. Jacobson “Observer responses to colour perturbations in reflection prints”, Imaging Science Journal 49, 81- 90 (2001).

Biography

Alan Hodgson has a BSc and PhD from the Department of Chemistry of the University of Manchester Institute of Science and Technology. He had over 20 years experience with ILFORD Imaging in Image Physics R&D, technical support and Sales & Marketing roles. In 2004 he left the role of Technical Services Manager, covering both traditional silver image and emerging ink jet technologies to start life afresh as an independent Technical Consultant on Non-Impact Printing.