The Differences in Characteristics of Dye Based Inkjet Images Subjected to Gas and Light Fading

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Abstract

The fading of inkjet imagery has been the subject of many studies. This study explores the differences between light and gas fading using a single dye based inkjet ink set. 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 focuses on one ink set as an example, a range of media has been examined in order to show the wide range of results that can be achieved. This illustrates the importance of the characteristics of the inkjet media in both light and gas fading behaviour.

The characteristics of light and gas fading have been investigated in isolation, but some consideration is also given to the more realistic case of real life imagery.

Introduction

In this study, the light and gas fading characteristics of a number of very different media, printed with a common inkset, have been explored. The inkset was a simple 4 colour CMYK set to avoid the complexities of aggregation behaviour found with light (dilute) inks.[1]

This study builds on some earlier work that explored the light fading characteristics of some of these media.[2] The set of media chosen for this study included a premium quality bond paper as an example of an absorbent substrate with an ink receptive surface layer. A cast-coated paper was also used. A glossy porous media provided an interesting contrast; this had low wettability but was effective at fixing dyes close to the surface while draining away the dye solvents. A swellable polymer coated paper provided an example of a different class of media, known to be very little affected by gas fading.

Previous work[2] with this ink set showed that the relative light fading of cyan and magenta inks was media dependent. In some cases the magenta ink faded more, in others the cyan ink faded more. In addition the density at which peak fading occurs changed with media type.

In addition, the previous work showed that the relative amounts of light and gas fading were ink dependent. It also explored the differences between light and gas fade characteristics.

Some of the media in the set showed substantial differences between light and gas fading characteristics, with the magenta generally giving a greater difference in curve shape between light and gas fading than the cyan. Figure 1 illustrates this for 2 different media printed with the magenta ink.

The light fade results were achieved using a 2 Mluxh Xenon arc exposure, filtered through window glass with humidity cycling as described elsewhere.[3] The gas fade results were achieved with a 28-day fade from a dark cabinet with forced air feed.[4]

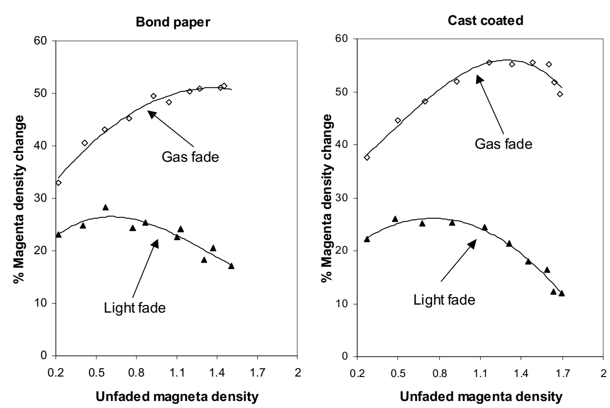

Figure 1. Magenta ink light and gas fading

Other studies have found similar results where gas fading reaches a peak and falls at higher densities.[5]

The purpose of this work was to identify the drivers influencing these curve shapes and thus gain a greater understanding of the parameters that influence these. The work may also have some implications for the setting of illustrative end-points.

Fading Curve Shapes – Light Fading

In this and the previous work[2] 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. One common metric of fading that is often used to determine illustrative end-points is the percentage change in Status A optical density[6]. In our earlier work polynomial statistics were fitted to the fade data and in most cases were found to provide a good fit. However, this work takes a closer look at these curve shapes. This can usefully be considered in 3 density areas; mid, low and high density.

Light Fading Curve Shapes – Mid Densities

Figure 2 shows the light fading characteristics of the cyan ink on the cast coated and polymer products, illustrated in two different fashions.

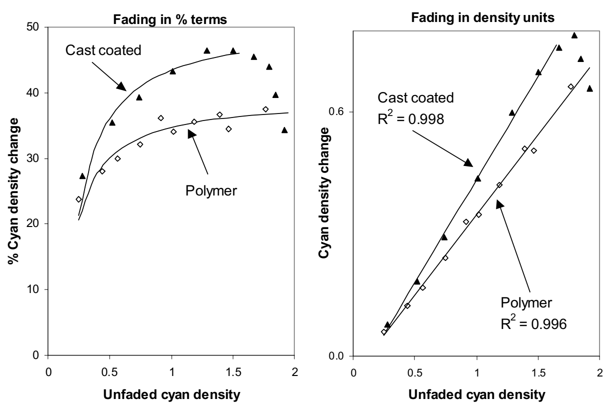

Figure 2. Cyan ink light fading characteristics

The left hand graph shows the fading in percentage density terms, as used in Figure 1. The right hand graph shows the same data but in this case the density changes are plotted as absolute units. It can be seen that at all but the highest density values the fading in density units is a linear function of unfaded ink density. This linear relationship holds for all ink loads on the polymer product but falls off at the higher ink densities on the cast coated. This linear relationship was used to compute the curves illustrated in the left hand plot.

Explanation

This linear behaviour can be explained as follows. Light fading is caused by the interaction of the dyes with the actinic part of the exposing light. To a good approximation the Status A optical density of the printed area should be a good measure of this interaction for one particular ink/media combination. Indeed it has been shown that the unfaded ink density is a good metric of fading for other ink/media combinations.[7]

Light Fading Curve Shapes – Low Densities

It can be seen in the left hand graph in Figure 2 that plots of percentage density change on fading can exhibit substantial curvature at lower densities. This is primarily an artefact of the arithmetic, as illustrated by Figure 3 for cyan ink on porous and cast coated media.

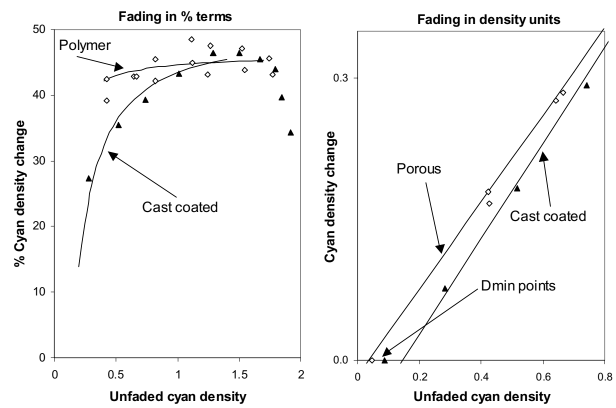

Figure 3. Cyan ink light fading at low densities

The presentation is the same as in Figure 2, except that only the low-density areas are illustrated in the right hand graph. This is to illustrate the fact that these lines do not go through the origin of the graph.

Explanation

This offset is mainly due to the fact that the density measurements are not compensated for the density of the unprinted media, commonly known as D_{min}. Although this compensation was normally applied to traditional silver halide based light fastness testing[8] it is often not applied for inkjet ink print permanence work.[1,6] As a result, when the linear relationship of the right hand graph in Figure 3 is divided by the unfaded density to derive the percentage figure plotted in the left hand graph, substantial curvature occurs at low densities. This reciprocal function is a function of the density offset (mainly D_{min}) on the x-axis of the right hand graph, which in this case can be seen to be greater for the cast-coated media. In instances where the offset is small or compensated for, the percentage density change plot is quite invariant with unfaded density – see the porous media in Figure 3. This type of relationship has been found for some other inkjet ink/media combinations[1] and for traditional photo colour papers.[9]

Also illustrated on this right hand graph of Figure 3 are the D_{min} values for the 2 media. It can be seen that for the porous media D_{min} lies on the regression line constructed from data points up to densities of 1.8. However, for a number of media including the cast coated illustrated here there is a substantial deviation – in this case nearly 3σ. We believe that this effect is probably due to optical spread function issues.[10] At very low densities light scattered or reflected within the layer may provide some additional fading, resulting in the non-linearity seen here.

Implications

The fact that D_{min} also varies with the Status A filter used means that uncompensated figures can show substantial differences between cyan and magenta ink curves at low densities – compare the cast coated media in Figures 1 and 2.

Light Fading Curve Shapes – High Densities

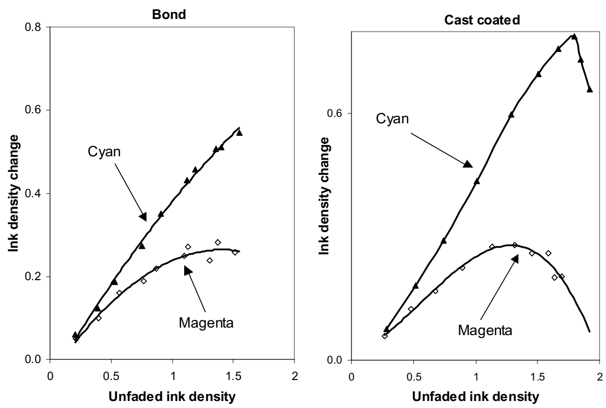

Figure 4. Reduction in fading at higher densities

Figure 4 compares the fading behaviour of cyan and magenta inks on bond and cast coated media, and illustrates the reduction in fading that is often seen at higher densities. This effect can be attributed to the presence of dye in excess of that amount required to fully cover the media surface ("monolayer" coverage) as explained below. Under these conditions, the excess dye provides a screening effect, reducing the overall degree of fading by comparison with lower dye coverage areas.

Explanation

As shown in Figure 4, the reduction in fading at higher densities is much more pronounced on the cast-coated paper than on the bond paper and in both cases is more evident with the magenta ink than the cyan. In order to understand this, it is useful to refer to images of the printed media. Figure 5 shows cross-sections through cyan printed areas for both media. Figure 6 shows the cyan and magenta ink spots at 40% ink loading.

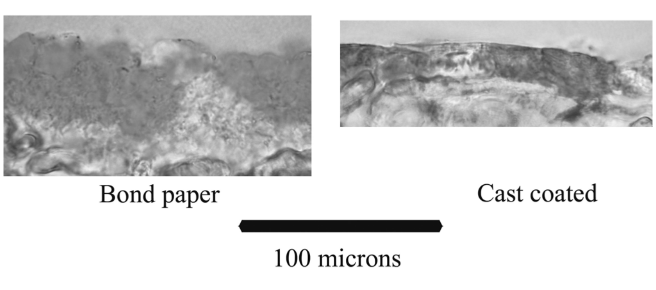

Figure 5. Cyan ink spot sections on bond and cast coated papers

The ink spots on the cast-coated paper are clearly more diffuse than those on the bond paper, providing more coverage of the available surface area. The cross-sections show that the dye is also contained in a thinner surface layer. This results in full coverage, and hence the onset of the screening effect, at lower ink loads for the cast coated paper.

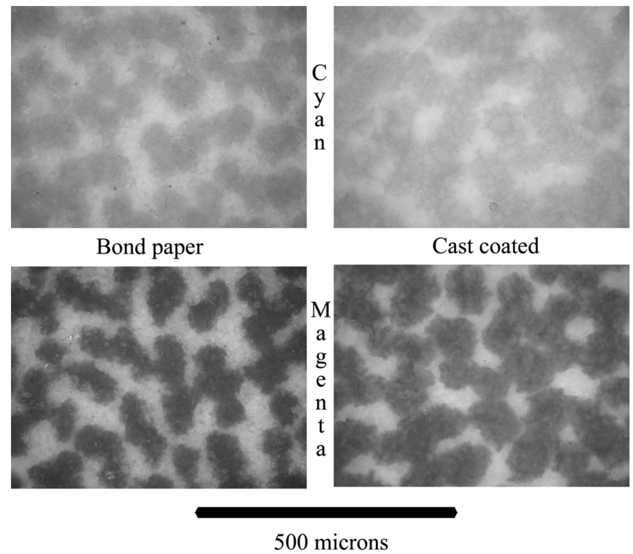

Figure 6. Ink spots at 40% ink load

This is further illustrated in Figure 7, adapted from some earlier work.[2] It can be seen that for the same ink loads the cast-coated material produces a higher density than the bond paper, due to the increased spot size illustrated in Figure 6. The equivalent plot for the magenta ink is very similar.

The magenta spots are not noticeably larger or more diffuse than the cyan ones, so the greater reduction in fading at high density must be due to other effects, possibly related to aggregation of dye molecules. The different sensitivities of cyan and magenta image areas to actinic irradiation have been discussed in earlier literature.[7]

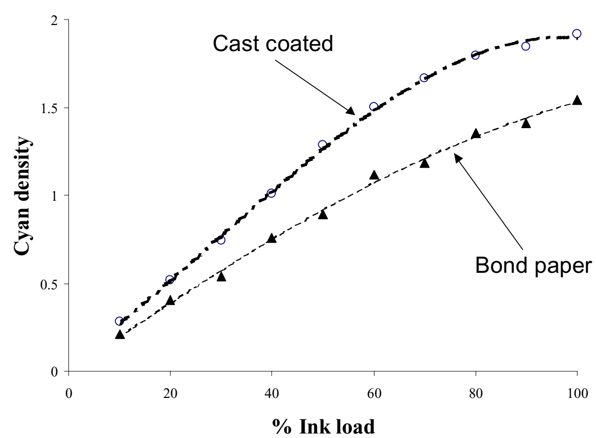

Figure 7. Cyan ink density as a function of ink load

Fading Curve Shapes – Gas Fading

In common with light fading, gas fading was found to be a function of ink coverage, in agreement with some earlier published work.[11] However, as illustrated by Figure 1, the curve shapes of gas and light fading can be very different. The purpose of this section is to illustrate these differences and to make some suggestions for the reasons for this.

Gas Fading Curve Shapes – Mid Densities

Figure 2 and the right hand graph in Figure 8 use cyan ink on bond, cast-coated and polymer media to illustrate that for light exposure the fading characteristics are typically linear over the mid density ranges.

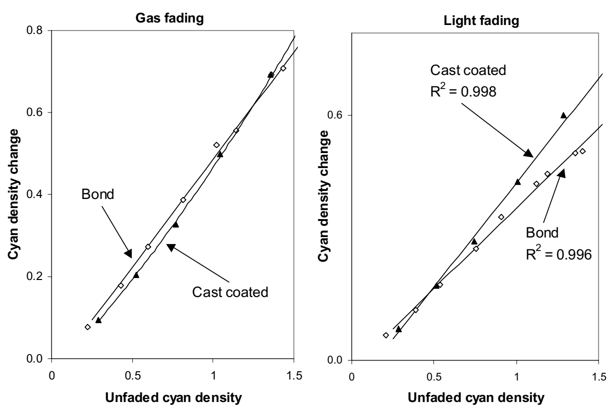

Figure 8. Light and gas fading at mid densities

However, as illustrated in the left hand graph of Figure 8, this is not necessarily the case with gas fading. In the cases shown here, whilst bond paper retains the "normal" linear characteristic typical of light fading, the cast-coated product data shows significant curvature. This was found with other ink / media combinations in this data set.

Explanation

As presented earlier in this paper, the initial (unfaded) optical density of the printed area should be a good measure of the susceptibility to light fading as this is caused by the interaction of the dyes with the actinic part of the exposing light. As a result we should expect graphs such as those in Figure 2 to be linear for light fading.

However, gas fading is not caused by exposure to *light* but by exposure to various *chemicals* in the surrounding air.[12] It is a chemical reaction between the dye and airborne contaminants such as ozone. We should therefore expect that, in common with other chemical reactions, the amount of fading to be a function of the *amount* of dye present in the image and the availability of the contaminants within the layer.[13] The convolution of these 2 (and possibly other) effects accounts for the non-linear behaviour observed here. It is probable that in common with some other photographic processes this fading is neither linear nor stationary in the mathematical sense.[14] Some of the issues around these 2 effects are discussed below.

Whilst optical density is some measure of the amount of dye present it does not reveal the complete picture. A better measure of the amount of ink present is the % ink load. The relationship between ink load (and hence the amount of dye) and optical density is illustrated in Figure 7. It can be seen that this relationship is commonly non-linear and media dependent. This relationship has been explored in an earlier paper[2] and is to do with ink spot size, as is further illustrated in Figure 6.

The availability of airborne contaminants within the media is also subject to a number of variables. These chemicals must firstly cross the air / media boundary. The surface natures of the various media used here are very different, as illustrated in Figure 9. Porous media has a different structure again.

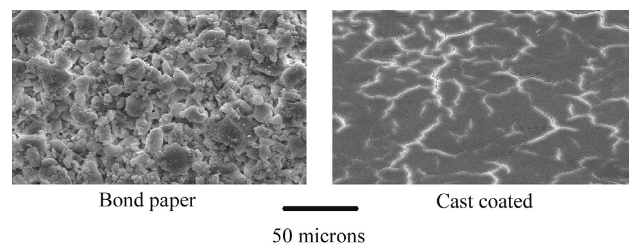

Figure 9. Surface nature of bond and cast coated media

The depletion of contaminants with depth will be a function of the distribution of the dye with depth in the medium chosen. This too will be media dependent, as illustrated by dyeing theory[15] and practical studies.[16]

Figure 10 shows cross-sections through the glossy porous product at 40% cyan and magenta ink loads, before fading, after light fading and after gas fading.

Prior to fading, both the cyan and magenta colorants are present in two distinct layers, an upper one that is sharply defined and a lower, more diffuse layer. This is likely to be a result of both the cyan and magenta inks containing two different dyes, which penetrate the ink receiving layer to differing degrees.

After light fading, the magenta can still be seen to be present in two phases, but the lower layer of cyan colorant has disappeared. This fits with experimental results on light fading of the cyan ink which show that there is rapid initial fading (the more fugitive of the two dyes) followed by a slower fade rate.[2]

By contrast, after gas fading, the two layer structure is still visible for both the cyan and magenta dyes, exemplifying the different mechanisms and characteristics of the two types of fading.

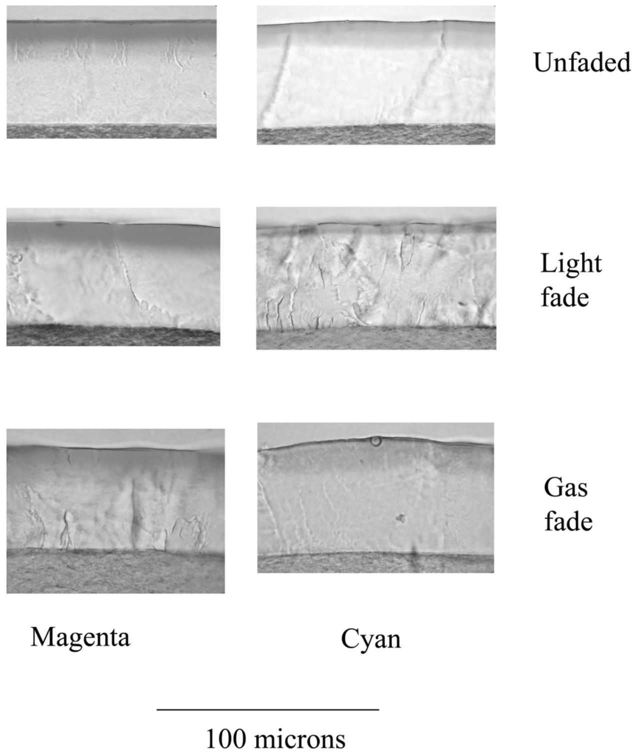

Figure 10. Sections of the porous media, faded and unfaded

Gas Fading Curve Shapes – High Densities

Figure 11 contrasts the behaviour of light and gas fading at high densities on bond and cast coated papers with cyan ink.

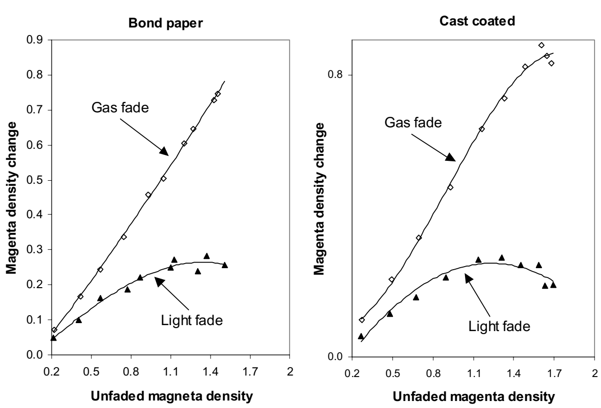

Figure 11. Light and gas fading at higher densities

As previously illustrated in Figure 1, the characteristics of light and gas fading are very different, particularly at higher densities. In the case of the bond paper the gas fade continues to increase with density but with the cast coated product the fade levels off. These differences between media can be attributed to different degrees of aggregation of the dyes at high densities that in turn influence gas fading.[12]

The Real World – Mixed Inks

In the sections above the various effects 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. Some of these are illustrated below.

Light Fading

Figure 12 shows the light fading of RGB colour patches, measured for cyan and magenta density.

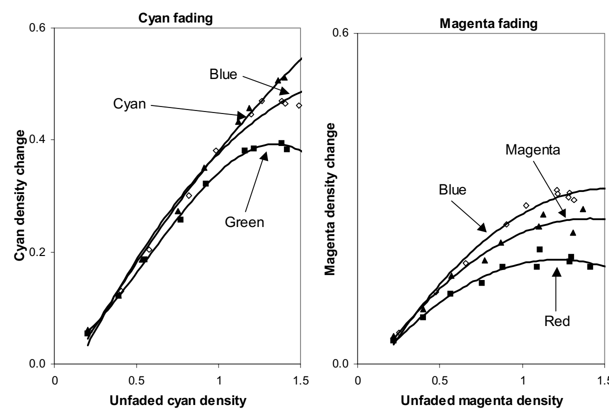

Figure 12. RGB ink light fading on bond paper

It can be seen that the introduction of yellow ink to form green (left hand graph) and red (right hand graph) introduces significant protection to both cyan and magenta inks, particularly at higher densities. This is attributed to the yellow ink absorbing the more actinic end of the spectrum, hence protecting the other inks. The actinic effects of shorter wavelength light, particularly on magenta ink have been noted elsewhere[7].

The mixing of magenta and cyan inks to form blue is a particularly interesting combination. It can be seen from the left hand graph in Figure 12 that the cyan ink in blue regions receives some protection from fading by the magenta component at high densities. However, the right hand graph shows that the magenta component is subject to enhanced fading over a wider range of densities through the mechanism known as Catalytic Fading.[11]

Figure 12 also shows that the cyan fading varies little with the addition of other components at lower densities. However, this is not the case with the magenta ink.

Gas Fading

Figure 13 shows the gas fading of RGB colour patches, measured for cyan and magenta density. These curves are in many respects very different to those in Figure 12.

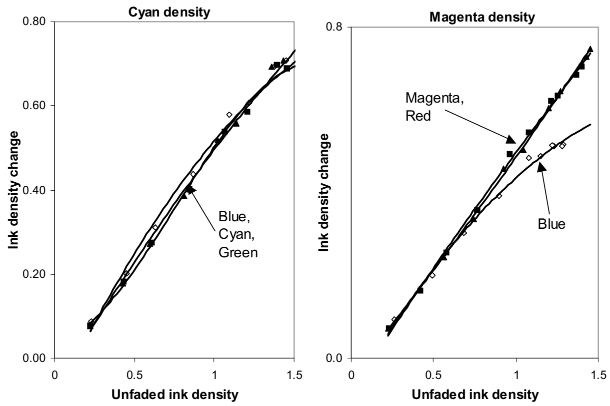

Figure 13. RGB ink gas fading on bond paper

In the case of the cyan ink (left hand graph) the amount of fading is constant irrespective of other inks present. However in the case of the magenta ink (right hand graph) the magenta gas fade is suppressed by the presence of cyan ink to make a blue patch.

These results suggest that for this particular ink set the atmospheric pollutants attack the cyan in preference to the magenta colorants.

Conclusion

1. Light and gas fade have very different characteristics, particularly at higher densities. Both are media and ink dependent.
2. If percentage-fading calculations are made without compensation for D_{min} then substantial curvature to the fading characteristic curves can result, reducing the apparent fading value, especially at low densities.
3. The factors influencing gas fade characteristic curves appear to be rather more complex than light fade.
4. Real world, or mixed ink, fading is very difficult to predict owing to the many possible interactions between inks, and to concurrent light and gas fading.

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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 Imaging 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.