A Visual Survey of Colour on Paper and Colour Changes During Exposure to Light

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Abstract

This paper presents how inkjet colour is affected firstly by the substrate and secondly what happens to ink on paper during exposure to indoor light conditions and air pollutants. The research uses both pigmented and dye based inks printed onto coated and uncoated fine art papers, and are subjected to light conditions that are constantly changing throughout the day and consequently the year. Although benchmark conditions and standards as issued by Wilhelm Imaging Research[1] are useful, once a printed artwork enters the public domain artworks may be subjected to conditions beyond expectations of the laboratory, such as changes in light, humidity and pollutants. Colour patches were printed onto a variety of artist's coated and uncoated papers, which are then measured and photographed. The microphotography shows how ink sits within the fibres of the paper, and how colour and colour combinations changes over time. The paper does not make approximations on the life expectancy of a print.

Introduction

The primary objective for this research is to provide an informed choice for artists intending to inkjet print onto quality fine art printmaking papers. Whilst there are fine art coated papers available, which are specially designed for inkjet machines and offer increased colour gamut and image clarity, the surface coating may reduce certain subjective qualities that are inherent to a paper.

From the perspective of an artist-printmaker who is used to handling different weights, textures, variances in base colour, there is an expectation that fine art papers can also be used through inkjet machines. However, due to the manufacturing process, how ink sits on the paper or in the fibres of the paper the quality of the image quality can show very different results.

Developments in inkjet technology have enabled the artist to print high quality photographic images; and through the use of wide format printing large-scale artworks has expanded creative vision. Similarly the ability to print, for example, banner sized works has also enabled a more professional means of presentation for exhibitions and display. Furthermore with this increase in scale artists are able to move beyond the frame,[2] which might include installation-based works, paper engineering and large format prints. To execute the work successfully an artist will require a range of suitable paper, both of surface quality and weight, accurate colour and tonal range, and colour that is consistent and conservable.

It is necessary at this point to consider users' expectations as to the longevity of printed artworks: fine art original prints require more colour permanence and subjective surface quality than for example a conference display, which is more than likely only required for the lifetime of the conference or exhibition. There is an imperative by artists to produce works that do not damage their reputation, both in terms of image quality and permanence. One could also consider the museum exhibition reproduction, for which there is an expectation by the buyer of a degree of colourfastness or permanence, but due to changes in fashion or interior design, may be discarded after a few years.

Furthermore a common misconception that an image printed with pigmented inks must be more lightfast than dye based inkjet inks. However some ink pigments used by the commercial offset litho industry, a commonly used method for printing posters, cards and book-jackets, can also be very fugitive. To illustrate this, I came across a display of greetings cards in a deli window in Rochester (see chapter entitled Lightfast Colour & fig. 1), the cards showed various stages of fading.

This paper does not present results on how long a print might last, there are tests undertaken by printer, ink and independent laboratories; however it is necessary to provide a context to lightfast testing. Standards and methods[3] of light fastness give parameters for testing; these results offer no more, no less a prediction. Accelerated lightfast tests are considered as a useful means of ascertaining the life expectancy of a printed image. Theoretically speaking, how long a print might last may be estimated through accelerated fading. How the image fades reciprocally is undertaken by increasing the intensity of light and reducing the exposure time, however the law of reciprocity is problematic[4] as there are many other factors that can affect fading. Therefore conditions under which lightfast testing is undertaken can offer results within specific parameters. Furthermore, there are many standards, used by different industries for measuring fade or colour difference: Blue Wool, Delta E, densitometry, all which can be considered within very specific parameters; and so far I have found no parity between the standards.[5]

Early tests[6] made at the CFPR showed how some inkjet prints might shift in colour and fade beyond acceptable levels as early as a few months. Subsequent tests have revealed that through a combination of appropriate substrates, colour profiling[7] and pigmented inks the longevity of printed works can be greatly increased.

In December 2001 a collaborative project was implemented with Hewlett Packard, and St Cuthbert's Mill, UK to produce the First International Digital Miniature Print Portfolio.[8] In order to ensure the digital prints were printed using the best inks and were compatible with the paper stock, we initially undertook an accelerated exposure using a Xenon arc lamp for 50 hours on a small range of uncoated and coated papers. Whilst the accelerated tests indicated pigmented inks were more stable on enhanced papers than dye based inks, we wanted to look at the relationship between paper and ink, to obtain a better understanding as to how ink faded, and to undertake a record of colour change characteristics. Real time testing obviously requires a long-term approach to a project. In March 2002, a second series of lightfast tests on a range of papers commenced, followed by a more detailed investigation in December 2002, which involved the use of colour measurements and the documenting of the surface of the paper through microphotography. The photographic recording offers a substantial contribution to providing a context and a better understanding of how ink and paper perform when combined.

An Analysis of Paper

For traditional printmaking, the variety of papers the artist can choose is vast and includes many permutations of weight, colour and texture. For inkjet printing the artist has access to a more reduced range of papers. However, since the initiation of this research, printer and ink manufacturers are introducing more papers. Most of the papers are being sold as a branded paper particular to the company and with modifications to existing coated papers already in production by the paper-mills. This is not to say that papers specially designed for inkjet are unsuitable, but do not always offer the right texture, weight or paper colour, appropriate for the 'job'.

In general, printmakers using traditional print processes are used to handling and printing onto quality fine art papers. Whilst particular coated matt fine art papers are designed to maximise colour and tone, an important consideration is the subjective nature of a paper, which is both important to the artist and the impact of the image on the viewer. Although bright, white, smooth, gloss or matt finishes offer the optimum conditions for saturation of colour and colour reflectance, which is an assumption made by printer suppliers; this is not necessarily the requirement for the artist. Some papers are suitable for a particular process and have certain characteristics, for example, manufacturing methods or fibre content, which may have an impact on how the ink settles in the paper fibre. Other considerations include the type of inkjet printer: Epson and Canon utilise Piezo printer head technology and HP printers use thermal heads. Therefore how the ink is deposited will also affect how ink penetrates the paper.

Whilst some users require a high turnover print production and a consistency of image, this does not necessarily mean that the image has a high subjective visual quality. By quality we mean, colour resolution, parity to the image on the screen, contrast, colour-range, subtlety of tone, continuous tone, good light tone, and how ink interacts with the paper. An initial evaluation of 66 fine art printmaking papers was undertaken. The papers ranged from lightweight Japanese tissues to heavyweight etching papers.[9] There was also a variation in the base colour of the paper, which ranged from a bright white to an antique cream. A test print containing a selection of art works, a grey-scale, fonts in varying sizes, CMYKRGB colour patches were printed onto the paper samples. The test sheet was generated in Adobe Photoshop in a LAB colour space, with no colour conversion in the print space. The selection of papers was not necessarily based on colour fidelity, especially as there was no original to compare. In fact papers that showed brightly printed results were not necessarily chosen. Papers were chosen for qualities relating to surface texture, ink capacity and the ability to hold detail without feathering; and lastly a paper that could have the potential for further development such as ICC profiling. Around 15 papers were chosen and included Japanese papers and samples from the Somerset, Arches and Fabriano mills, which are further being trialed in combination with enhanced papers for lightfast testing; and in collaboration with the UK's primary paper merchant for fine art papers to write colour profiles.[10]

Lightfast Colour

As mentioned in the Introduction, colour fading is not limited to inkjet. To ensure prints do not fade the obvious answer is to use best possible materials. A common misconception is that oil based pigmented colours provide the maximum permanence. However, as an example, three cards printed by offset litho reveal how over approximately ten years, magenta and yellow fade resulting in an image that is predominately blue. A common problem inherent to many CMYK inks, including inkjet, cyan and black are the more permanent, magenta and yellow can still be fugitive. (fig. 1) The cards in the deli in Rochester, based on their position in the card stack and customers moving the cards around, illustrates how the first card, which remained at the back of the stack and therefore received the least amount of exposure retains all the process colours; the second card, which received a relative amount of exposure the yellow is lost; and the third card encountering the most amount of light the magenta and yellow is absent.

For our printed samples, colour tests were undertaken using dye and pigmented inks onto artist's 100% cotton based handmade, uncoated and matt-coated inkjet papers. The printed tests were exposed to light conditions that simulated a gallery, work or home environment[11] around 300 – 600 lux. The light conditions varied from 50-100 lux on a dull winter day to 400-600 lux on a summer day. Lux measurements were taken from a white target of an indirect reflected natural illumination from a northeast facing window. The samples were not subjected to any direct light. These considerations, whilst based not under laboratory conditions in which the light source is constant, are based on many gallery conditions. For example artworks exhibited at the 150-year Royal West of England Academy in Bristol, which was constructed with vaulted glass ceilings can expose artworks to extreme intensities of light and heat, especially in the summer (albeit short). Other works may be presented in gallery windows or under strong halogen lights. The Museum and Technical Alliance recommend allowable light levels in museums for particular artefacts and artworks[12] but these are invariably overlooked for short-term exhibitions or commercial events. Artworks in exhibitions are invariably only subjected to such conditions for the length of the exhibition.

In March 2002, thirty-seven papers were printed, including six coated papers - some of the more popular artists' printmaking papers - to which an ink receptive layer is added. Colour samples containing Cyan, Magenta, Yellow, Black and CMY patches at 5% increments were printed using Hewlett Packard UV (pigment) inks and dye-based inks on a 42" HP5000ps. The objective to this test was to make a visual assessment of the samples over the year.

In December 2002 a further set of samples were printed. An ongoing methodology involves colour difference measurements and photo-documentation. Initially measurements on patches containing 50% ink coverage were undertaken every two weeks; since June 2003 measurements are recorded once a month. The patches are measured using a Gretag Macbeth spectrophotometer using an illumination D50 and at an observer angle of 2°, so that colour patches are accurately measured and compared. ∆E*ab colorimetry is the preferred method of measuring and comparing changes in colour, and is based on the CFPR's working methodologies used for colour management, image processing and colour profiling. Colour patches are also photographed using a SP-200xm metallurgical microscope that has a reflective light source, and is designed for non-transparent samples. The microscope light source illuminates the surface of the sample from above. Colour patches are photographed under 10/2.5 magnification using a Canon G3 digital camera.[13]

A 0.09mm x 0.15 mm section (fig. 2) taken from a 2.5mm diameter sample is equivalent to 40 x 50 mm in the printed colour insert. The digital images are converted to Tiff files and saved with no compression to ensure accurate, accessible colour data. Cyan, magenta, yellow, red, green, blue, black colour patches at 50% ink levels and a composite black patch at 100% are photographed.

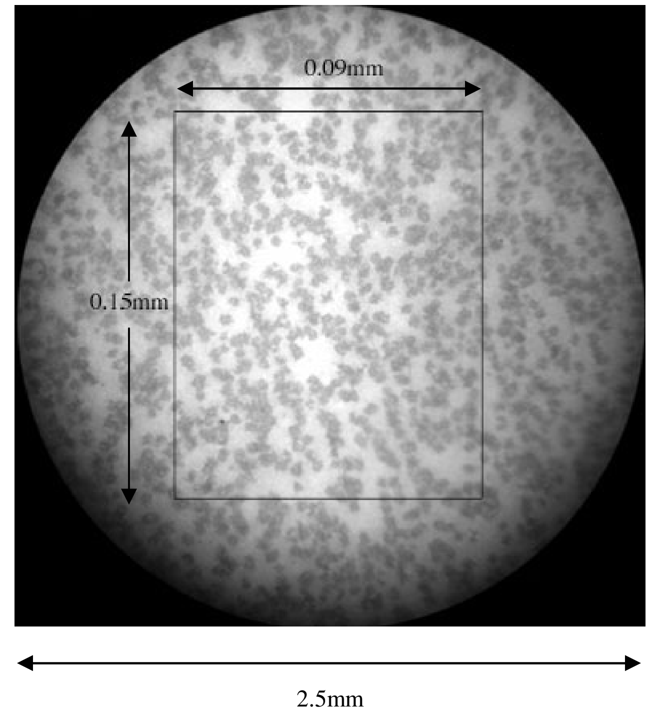

Figure 2. Sample under microscope and equivalent measurements.

Tests Begun in December 2002

CIELAB colour differences are recorded between recently printed samples (reference data) and exposed samples (measured data). ∆E*ab averages are calculated here showing the average difference in colour changes between CMYK, uncoated and coated, dye and pigment.

Average ∆E*ab differences after 4 months:

Dye	Cyan	Magenta	Yellow	Black
Coated	9.74	11.84	10.16	0.48
Uncoated	1.72	4.33	1.33	0.62

Pigment	Cyan	Magenta	Yellow	Black
Coated	0.7	2.02	1.23	0.55
Uncoated	0.9	1.86	1.04	1.14

Average ∆E*ab differences after 8 months:

Dye	Cyan	Magenta	Yellow	Black
Coated	25.3	52.8	14.6	0.8
Uncoated	6.5	17	6.12	1.1

Pigment	Cyan	Magenta	Yellow	Black
Coated	3.5	5.3	1.6	0.6
Uncoated	3.1	4.2	1.4	0.9

The results suggest that the magenta is problematic for all papers. Over time the reduction in magenta, results in a greenish blue cast to the prints. Furthermore as the black is the most resistant to fading, contrast in the dark tones and highlights will become more extreme. Similar to the printed litho samples, as the cyan and yellow are also resistant to fading the prints will take on a greenish tinge. The fading rate for pigmented inks appears to be consistent for both coated and uncoated papers.

A Visual Assessment

A visual comparison between coated, uncoated, dye based and pigment paper samples was undertaken; particular details are noted here:

Pigmented inks on coated and uncoated papers:
- 5% colour patches are still visible including samples printed in March 2002
- A slight reduction in intensity for composite black patches
- Slight reduction in vibrancy

Dye inks on uncoated papers:
- Colour intensity is moderately reduced
- 5% patches are still visible
- Colour appears to be slightly duller
- Composite grey patches up to 75% ink coverage show a shift to a greenish grey, as do the composite black patches

Dye patches on coated papers:
- 5% and 10% ink coverage cyan colour ink patches are not discernable, and magenta ink patches for up to 80% on some coated papers are not apparent
- Overall colour intensity is very reduced
- Composite blacks and greys appear olive green
- Appearance of colour mottling and non-uniform fading (fig. 7)

A comparison between pigment inks onto coated, uncoated paper reveals there is very little noticeable colour shift. Although there is a reduction of colour for dye-based inks on uncoated, dye-based inks are not compatible with the fine art coated papers and should be avoided.

Other Indications That Affect Colour Changes

Colour measuring has also highlighted samples that have darkened. Subsequent measuring of the paper[14] has indicated that Japanese samples, indicate a darkening or yellowing, suggesting that the fibre content can contribute to colour difference. Some of the accelerated lightfast tests (2001) yellowed the surface of the brilliant white-coated papers, although this has not occurred during any real–time tests. There was an assumption that ink on papers made by the same manufacturer would fade at the same rate. This has not always been the case. Different manufacturing processes, such as the texture, sizing and construction of the paper can contribute or inhibit the fading process. Another suggestion is the chemical effect of one colour on another. When printed separately a colour retains fidelity, however when combined with another is weakened and becomes more fugitive. The slight rise in colour difference for uncoated papers might indicate anomalies such as darkening of Japanese papers and possible chemical reactions occurring with differing manufacturing processes.

Observations Under Microscope

Papers that are coated or infused[15] have a receiver layer that holds the ink droplets close to the surface, the surface of the paper is generally much brighter and smoother, and reflects colour more successfully than uncoated papers. For an uncoated paper the fibres are still visible and the ink falls within the peaks and troughs of the fibres, the colour is reflected in different directions therefore making the image duller and flat. This can be also compared in the microphotographs where the light shining onto the coated samples is displaced evenly, whereas the light source falls unevenly onto the uncoated paper samples, making some areas 'glow' (fig. 5) and some areas appear dark. Uncoated papers are also more difficult to photograph. The surface is more uneven and due to the level of magnification and depth of field some areas are therefore out of focus.

Dye and pigment based samples printed onto coated and uncoated papers reveal two differences: the surface structure of the coated and uncoated papers (fig. 4 and fig. 5) and the impact of cyan on other colours (fig. 4 *50% grey pigment ink* and *dye ink*). There is a discernable difference between the dot structure on the coated (fig. 4) and a more crystalline structure of the uncoated (fig. 5) in which the ink has been absorbed into the paper fibres. This is all the more exaggerated in for example a Japanese Tosa Shoji paper (fig. 3), which has a much looser weave, and illustrates the network of fibres and how the ink is encapsulated within the fibres. Looking at this sample under a microscope creates a three-dimensional effect.

The photographs taken at the beginning of the test period, and subsequent photographs made of samples that have had 17 months of exposure, illustrate which colour has a tendency to fade. After 4 months (fig. 4, *dye ink after 4 months*) the dye colour on the coated paper sample is paler. There is also a problem with mottling. As mentioned in the section A Visual Assessment, (fig. 7 and fig. 4, *dye ink after 4 months*) colour samples do not fade uniformly, but become patchy. Under the microscope, the surface topology of an uncoated fine art paper is uneven, due to longer fibres and form peaks and troughs. A suggestion might be that during the coating process any irregularities are filled to create a smoother, more even surface. There is a possibility that over time dye inks react to the different levels of coating and therefore fade at different rates. After 17 months the dye sample printed at 50% (fig. 4, *dye ink after 17 months*) cyan and yellow dots are just visible. For composite grey (CMYK) samples on uncoated papers (fig. 5) we can compare the pigment ink and how it has changed after 17 months, with the dye and dye inks after 17 months. There is a slight reduction in colour intensity, but the black dots have not faded, this is further exaggerated in the dye sample. Similar characteristics can be observed in fig. 6 (M+Y dye ink and M+Y dye ink after 4 months) the magenta has faded and the yellow more resistant, resulting in a more orange appearance.

Under magnification, an interesting anomaly as to the behaviour of ink on paper was the appearance of a crackle effect in which patches of ink appears to craze (fig. 6, *pigment grey ink on Bockingford Inkjet*). During a particular coating process in which papers are infused, the coating used to create a smoother surface may cause the printed ink to dry at different rates. So far this surface artefact has not contributed to fading or colour change. A further point to consider is the problem of dust. Dust particles were detected on papers that have a *velvet* surface. This could also contribute to the dulling or soiling of the paper surface of works such as artists books, which can be affected by handling, or paper constructions that might be subjected to dusty conditions.

Conclusion

Lightfast tests are useful for suppliers and consumers to gain an approximation of a printed image's life expectancy. However we must consider there are other influences that determine how the artwork will look and change. The substrate and coatings also have a significant affect on an image. There is a difference between the artist who is looking for a quality of surface, which might include texture and base colour, and the commercial user who might require a consistency of reproduction and colour reflectance. So far investigations have concentrated on thermal prints, but subsequent studies will involve the documentation of Peizo head technology.

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Double printed black pigment	Density: 2.33	ΔE: 20
Dye	Density: 2.24	ΔE: 21
Pigment	Density: 1.81	ΔE: 24

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Biography

Carinna Parraman is Research Fellow at the Centre for Fine Print Research, UWE Bristol UK. Her research includes digital printing methodologies for artists and an investigation of colour used by artists in the 1960s and 70s. She is academic supervisor for a government-funded programme, writing colour profiles for artist's fine art printmaking papers. She has collaborated with Hewlett Packard Art and Science programme on a number of projects and she recently coordinated the HP colour and wideformat masterclass symposium, which was presented in collaboration with CII University of Derby and HP.