The Equivalence of Light Sources in Light Stability Testing

Eduard Baumann and Rita Hofmann
ILFORD Imaging Switzerland GmbH
Marly, Switzerland

Abstract

Light exposure of colorants with light of different spectral characteristics was investigated. Typical spectra of light sources used in accelerated light fading, filtered xenon arc and cool white fluorescence were area- normalized to the same lux level or the same total energy. The light absorbed by each colour channel was compared for the two cases. Using cool white fluorescene illumination at same lux level is about 50-65% as efficent as using indoor filtered xenon arc. The efficiency depends on the colour channel and is not very dependent on the exact dye spectrum and not very sensitive to the exact spectral composition of the light source. Comparisons with experimental data confirmed that the degradation of the colorant was dependent on the spectral power distribution of the light source and the absorption characteristics of colorants. For the cases where the experimental fading light source varies from the assumed display condition, the authors propose an approximation, that converts the exposure from one light source to another per colour channel. Two light sources are roughly equivalent as long as the area normalised spectra per colour channel are the same.

Introduction

It has long been required that fading experiments are done with exactly the same exposure light as the print will encounter in real-time fading. However, natural fading often does not have a clearly defined light source, as daylight varies over time/season and location. Also indoor light is a varying mixture natural light and different types of artificial light. Every display location has its special varying and different exposure condition. In accelerated indoor light stability testing, well controlled light sources like Xenon arc or cool white fluorescence lamps (Fig. 1) are used to fade prints to a chosen end point.[1] For indoor fading, the limiting Mega lux hour (Mluxh) level to achieve noticeable fading is often used to extrapolate to similar fading under lower illumination of real-life displays. As typical lux illumination levels are known for many display environments, lux is a convenient unit to describe indoor display conditions. In outdoor light fading, the changes in the materials after reaching a certain total energy of exposure are often preferred to describe light stability.[2] In both cases one single number is used to describe the light exposure for all colorants. Both approaches disregard the spectral difference that exists in different types of daylight or artificial light and the effect that this has on colorants. A difficulty in the extrapolations from accelerated to real-time fade is the fact that the light source in accelerated fade will very probably be different from the light source that illuminates the print on display. Outdoor daylight and indoor daylight through window glass are not well-defined constant illuminations. Only recently has representative indoor lighting been investigated in typical homes, showing that the average indoor light does not correspond to any of light sources used in accelerated tests today.[3]

In Ref. [4] the authors describe an approach to use actinic spectra for the prediction of life of print. While this is the most exact method, it is difficult to determine action spectra for the many colorants and coloured prints in use today. The method described in this paper does not attempt to predict actual life of display of prints. It proposes an approximation to convert fading data established with one light source to expected fading under a different illumination. The method is limited to indoor illumination with a very low amount of UV light present. If the UV content of two light sources is very different, the assumptions for the estimation are no longer valid. Because the approximation is a relative method it does not need the intricate knowledge of action spectra and avoids many of the difficulties that an absolute estimation of fading would bring. The idea is based on the fact that colorants absorb only in certain areas of the spectrum and that only light that is absorbed can contribute to fading.[5] The visible absorption spectrum shows the transition of a colorant molecule from its ground state to an electronically excited state. For most of the organic molecules used as IJ colorants, the energy of visible light is not high enough to break a bond directly. The serious degradation observed in colour light fading of prints is caused by chemical reactions of the electronically excited state of colorant molecules which has very different reaction mechanisms from the ground state and is much more reactive.[6] The excited state can undergo various reactions with air or layer compounds in the matrix. However, light with lower energy than the absorption band will not lead to the excited state, but contribute to thermal heating of the sample. Although this thermal degradation may finally degrade the sample as well, the ground state reactions are generally much slower and of lesser importance in light fade. On the other side of the spectrum, the higher energy of UV light may break chemical bonds directly by photolysis and different photochemical reactions and reaction mechanisms will occur.[7] This is why the estimation described in this paper should not be extended to light sources with strong UV emission.

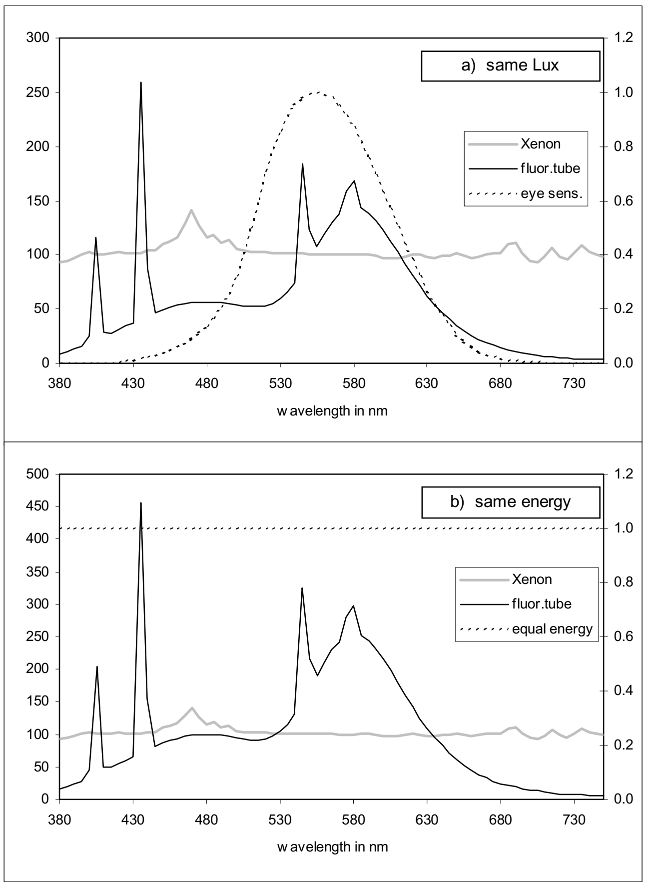

Figure 1. The two light sources Xenon and cool white fluorescence shown for equal area in Lux (a) or energy (b)

Theoretical Considerations

Two typical light sources used in accelerated fading, filtered Xenon-arc lamps and cool white fluorescence lamps, are represented in Fig. 1a and b in arbitrary units. Also shown are the eye sensitivity curve used to convert the light spectra into lux units in a) and the equal energy curve used to normalize the two light sources to the same energy in b). As can be seen from the short (<530 nm) and long (> 630nm) wavelengths range in the graph, normalization to equal lux underestimates the blue part of the spectra, which are in fact the more energetic and more destructive parts in dye fade as well as the red parts of light relevant for the cyan dye. Normalization to same energy produces more green emission, while leaving blue and red areas similar to xenon arc light.

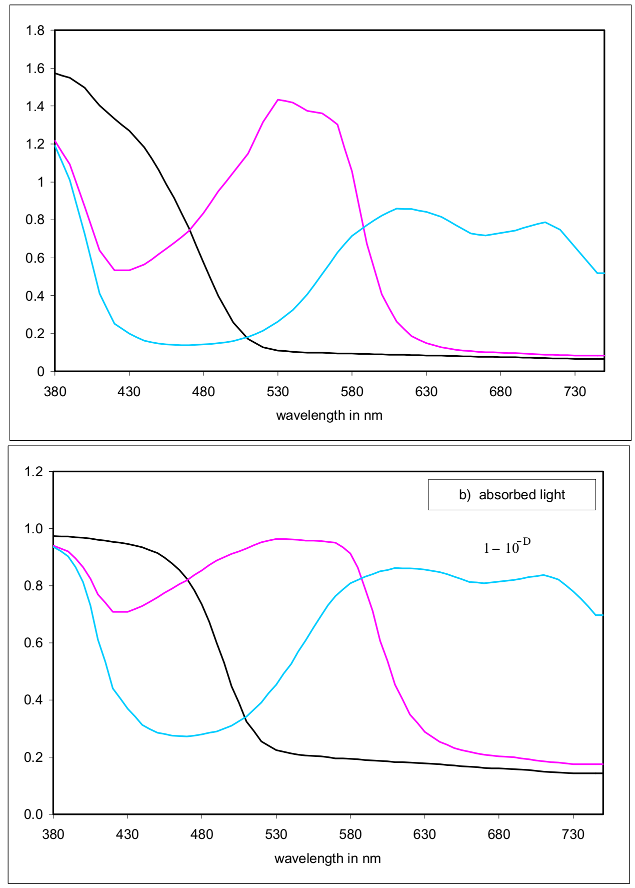

Figure 2a,b. Typical dye absorption spectra for Y, M and C

Typical dye absorption spectra for Y, M and C ink-jet dyes in absorbance are shown in Fig. 2a. The chemical background described above is the reason why only the part of illumination in the visible wavelength range of the absorption band of a colorant is regarded for the comparison of two light sources. If we assume that only absorbed light will contribute to dye degradation, the dye absorbance needs to be converted into the linear absorption of light by the function $1\text{-}10^{-D}$ with the results shown in Fig. 2b. The measured absorption spectra of the printed dyes are not a direct measure of the light absorbed by the dyes alone. Some of the light may be scattered or absorbed by the media.[8] However, for the theoretical consideration such scattering effects were neglected as the methods were shown to be quite insensitive to fine variations in spectra. For the later comparison of theoretical predictions with experimental results, print patches were chosen that have nearly full dot coverage. In addition, the study concentrated on photo-like glossy media which have transparent receiving layers, so that the light scattering of the media is rather small compared to dye absorption and can be neglected for the purpose of the estimation. For plain papers or matt pigment coated papers some assumption may not be valid.

The parts of the illumination spectrum that overlap with the absorption spectrum of a dye are most important for the fading of the dye.[5] Figures 3a,b,c and show the areas of overlap (convolution) for typical Y,M,C dyes with each of the two light sources, Xenon arc and cool white fluorescence, normalized to the same irradiance in lux. The total exposure for the three dyes is considerably smaller in the case of fluorescent illumination than of Xenon-arc illumination. Assuming linear behaviour with exposure and little deviation from reciprocity[7] we expect the fading to be correspondingly reduced under fluorescent light of the same lux value.

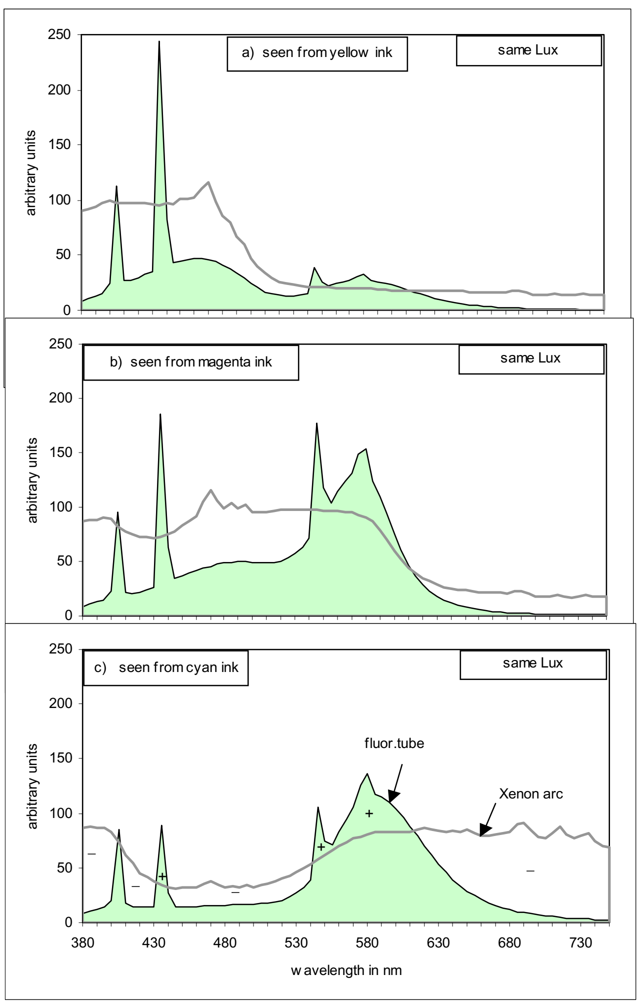

Figure 3 a, b, c. Areas of overlap (convolution) for a typical Y, M, C dye with each of the two light sources, Xenon arc and cool white fluorescence

Several model dye sets were investigated to probe the sensitivity of the approximation to the dye spectra or light spectra used. For case study I-V in Tab. 1 the xenon arc and cool white fluorescence sources as shown in Fig. 1 were used.[9] The percentage of exposure in cool white fluorescence compared to xenon arc was calculated for different cases. The base case (I) is the exposure of the typical dye set 2b. In case (II) the cyan dye density was doubled compared to case (I). In case (III), the three typical dye spectra were replaced by block dye spectra with cutoff limits at 500, 600 and 700 nm. In case (IV) the long wavelength absorption of cyan was cut at 630 nm. The simulation for different dye spectra shows, that it is not sensitive to the exact nature of the dye spectra. This is because it is a relative method. It may thus be applicable as an approximation to many dye sets. In the last case (V) the two light sources were normalized to the same irradiance in MJ/cm2. This irradiance specification is often used in outdoor fading to compare experiments and define the limiting exposure.[5] For the change from xenon arc to fluorescence illumination, normalization to equal energy irradiance has a different effect than normalization to lux. The yellow and cyan are not much affected by the change in light source, but the magenta dye is. The normalization to equal energy of the two light sources does not produce the same exposure for the three dyes. The difference in the spectral power distribution continues to produce less efficient fading in some dyes than in others.

Table 1. Relative Efficiency of Fluorescent Light (Xenon = 100%)

	Equal	Yellow	Magenta	Cyan
I	lux	54 %	69 %	56 %
II	lux	54 %	69 %	57 %
III	lux	50 %	72 %	65 %
IV	lux	54 %	69 %	61 %
V	energy	95 %	121 %	98 %

Experimental Results

The approximation was used to compare light fading in an accelerated Xenon-arc test at 50 kLux with a fluorescent light exposure at 6 Klux. The fluorescent light source was cool white fluorescence filtered by a diffusing screen. The actual spectrum was measured by an Ocean Optics USB2000 spectrometer. A third test was run in natural display in a library with mixed daylight and artificial light. The natural spectrum was not measured. All three tests were run at 45-55% r.h. A set of 4 polymer media with 4 different dye-based inks was used as a test set. Polymer media were chosen to reduce the level of ozone fade that may occur in longterm studies. The test image consisted of wedges of 9 steps printed in y, m, c and k. The k channel was either a mixture of 3, 4 or only one colorant, dependent on the printer driver used. For every ink/media combination, the changes in density of y, m, c, k at 0.5 density (CL, ML, YL, KL) and Dmax, varying from 0.8 to 2.5 density (CD, MD, YD, KD) were plotted at exposure intervals of 2.5, 5, 7.5, 10 and 20 Mlux for the accelerated condition Xenon arc and fluorescent light. The color changes were measured in status A density and spectrally on a Gretag Spectrolino spectral densitometer.

Typical relative density loss plots for one ink/media combination and the three illumination sources are shown in Fig. 4a -c. The data are reported for the same lux levels of the three light sources. Fig. 4a is the graph of the lower density colours CL, ML, YL, KL of the print exposed by xenon arc light. Fig. 4b is a plot of the same colours after the fluorescent light exposure. These examples show the apparent higher rate of fade of the xenon arc test compared to the fluorescent light test in one single case.

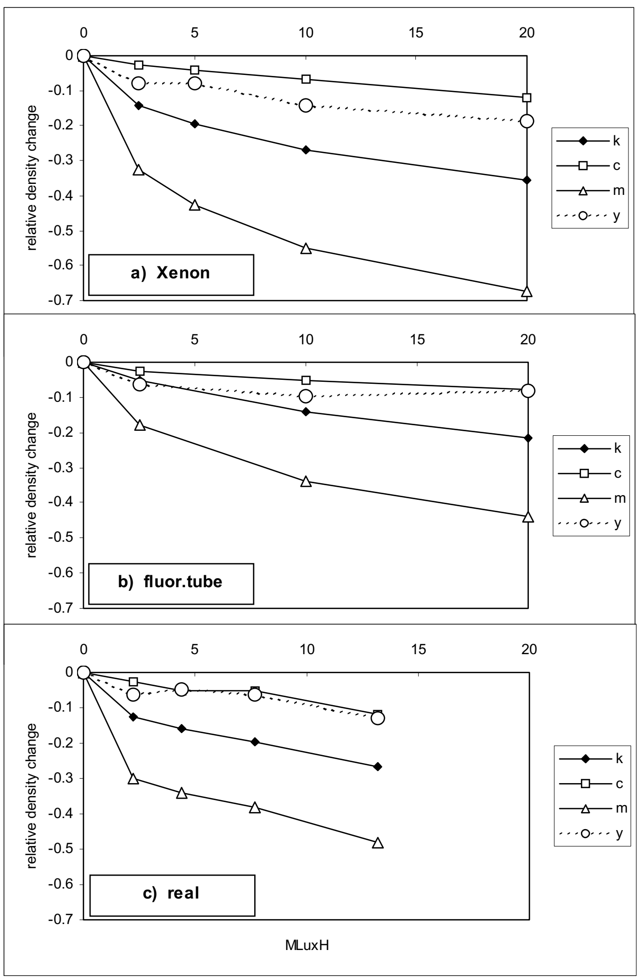

Figure 4 a, b, and c. Typical fading curve for one ink/media combination for the three light sources

The study was then applied to the full sample set. For all 4 ink/media combination and per colour, the relative light efficiency for the two light sources was calculated and averaged for the 10 Mluxh and 20 Mluxh exposures. These averages are plotted in Fig. 5 together with the predicted light efficiency from case (I) in table 1. The agreement between predicted efficiency and measured fading efficiency is quite good. It has to be borne in mind that the overall illumination level of the two exposures varied by about a factor of 10 and the corresponding color patch temperature and humidity were certainly different. Different dye diffusion and fading reactions other than light cannot be fully excluded for the trial.

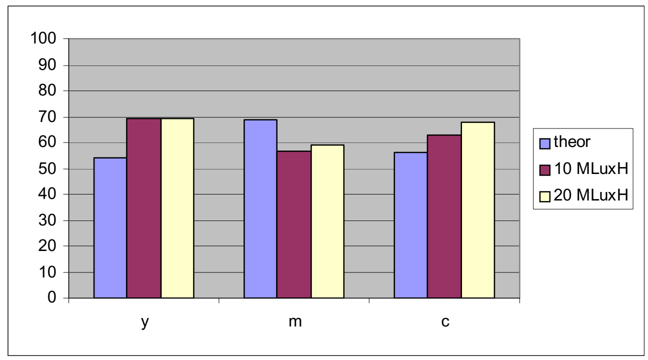

Figure 5. Relative efficiency of fluorescent light for different dyes compared to xenon light

Ink jet black can either be a single colorant or a mixture in the ink or a mixture of Y,M,C printed dots. A black colorant molecule will absorb light over the whole range of the visible spectrum. Such a colorant should be more sensitive to a change in light source than a composite black, in which every individual colorant only absorbs part of the spectral range, thus being affected by only part of the difference between the light sources. A smaller difference in changing light sources is indeed observed and shown in Fig. 6 for a composite black patch compared to a single colorant black. After fluorescent light exposure, the single color exhibits a difference in fading of 64% when compared to Xenon arc, the composite black only 53%.

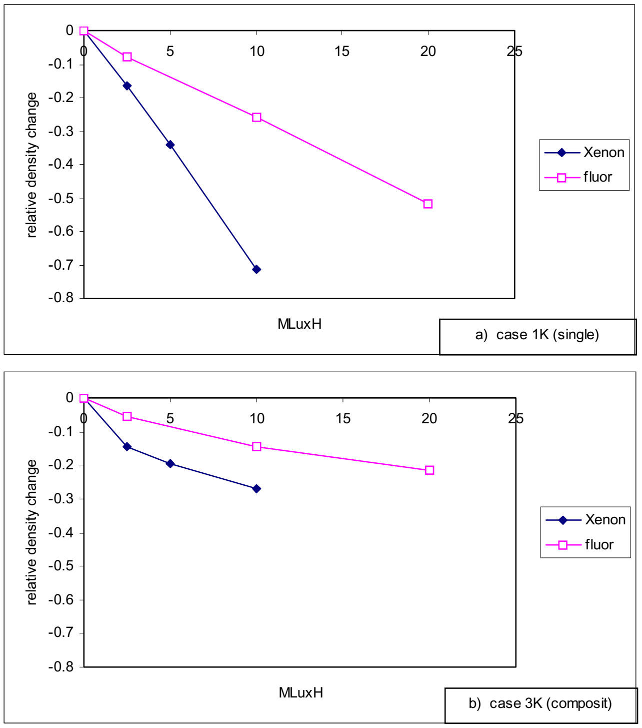

Figure 6 a, b. Fading curves for the two types of black (single and composite) for two different light sources

The results of the accelerated light fading study on the two light sources were finally extended to real life fading over several years. A third sample set was displayed in averaged 1 kLux natural daylight exposure in a library facing North/East placed at 2 m from a window over a period of 3 years roughly corresponding to 13 Mluxh. The samples displayed in the library were measured after 6, 12 and 21 and 36 months. For the ink/media combination used in 4a and b the fading curve of library display is shown in (4c). There is considerable uncertainty about the exact nature of the spectrum as well. Although the real fading data do not match any of the accelerated curves exactly, they are closer to the fading in Xenon arc light.

Conclusion

Qualitative calculations show that when dyes are exposed to light sources area-normalized to the same Lux or energy level the amount of light actually absorbed will differ appreciably as a function of the dye spectrum. This confirms the rule that predictions for life expectancy can only be done if accelerated exposure light and predicted display light match closely. Another possibility is to determine the action spectra for every dye and calculate the sensitivity to fading. In practice any of the conditions is difficult to achieve. The study shows a simple approximation how to compare the efficiency of two light sources if only the dye absorption spectra are known. For the two most widespread light sources used in accelerated fading test, xenon arc and cool white fluorescence, and typical IJ dyes, an average ratio of exposure can be estimated per color channel. Normalized to the same lux level, the yellow, magenta and cyan channel will typically only have been exposed to 54%, 69% and 56% of light respectively under cool white fluorescence. Normalized to the same total energy, y, m and c will have been exposed to 100%, 120% and 100% of light compared to xenon arc exposure. These ratios are not very sensitive to small changes in dye spectra or illumination spectra. The method has been validated on actual photo-like IJ media exposed to different light sources. The 6 steps of the approximation to calculate exposure ratios can be summarized as follows.

a) Measure the relative spectral power distribution of the light sources and normalize them for comparison
b) Measure the dye absorbance spectra at printed medium to high density patches
c) Convert dye absorbance spectra b) into linear light absorption by the function $1\text{-}10^{-D}$
d) Multiply the exposure lights with the linear light absorption
e) Divide the area under a curve for the second light source by the corresponding area of the first light source. The ratio compares the relative light absorbed for the two light sources.
f) Assuming linear fading and good reciprocity, divide the color density loss by the ratio per channel. It gives the expected fading for the new light source.

The life expectancy is determined by the weakest color. First the single color fading needs to be converted as described in a)-f). Then the fastest fading color and the exposure to reach a defined end point can be determined for display lifetime calculation as usual.

Acknowledgements

The authors would like to thank Juerg Reber for the spectral characterization of the light sources and Jean-Pierre Beyeler for the experimental data.

References

1. American National Standards Institute, Inc., ANSI/NAPM IT9.9-1996, American National Standard for Imaging Materials – Stability of Photographic Images – Methods for Measuring, American National Standards Institute, Incc., New York, NY; 1996
2. ASTM research report D-1, 1036, Standard Practice D 4303, 1994
3. D.E. Bugner, M. Oakland, and R. Willard, IS&T's Thirteenth Internatl. Symposium on Photofinishing Technology, Las Vegas, NV, 2004, page 33
4. G. Van Ackere, H Kanora, M. Graindourze, H. Friedel, and S. Lingier, Interpretation of Life-of Display Predicton Calculated from Accelerated Light Fading Tests, IS&T's

Internatl. Conference on Digital Print Technologies, NIP 17, 2001, page 213
5. George Wypych, Handbook of Material Weathering. 3rd edition, ChemTec Publishing, 2003, page 7
6. Paul Suppan, Chemistry and Light, The Royal Society of Chemistry, Cambridge 1994
7. R.L. Feller, Accelerated Ageing, The Getty Conservation Institute, 1994,
8. Wiszecky & Stiles, Color Science: Concepts and Methods, Quantitative Data and Formulae, Wiley 1982
9. R.W.G. Hunt, Measuring Colour, 3rd edition,Fountain Press, Kingston-upon Thames, 1998, page 266

Biography

E. Baumann studied physics at Fribourg University in Switzerland. He joined ILFORD in 1968 and has worked in the area of photographic sensitometry, color science and image quality. He has published several papers in this field. Since 1985 he has been active in digital imaging, first in the digital exposure of photographic papers and films later in ink-jet media and materials with a focus on colour science and test methods.