Interpretation of Life-of-Display Prediction Calculated from Accelerated Light Fading Tests

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Abstract

The present ink jet technology permits to replace the traditional imaging colour technology for which image permanence is of crucial importance. Several test methods and standards have been developed to judge image permanence on accelerated ways for indoor as well as for outdoor applications. Especially for light stability, these methods are based on the conventional law of time-integrated illuminance. In this paper we will show that, rather than the light dose, the UV & VIS irradiant exposure energy in combination with the material's action spectrum, image optical density, relative humidity and temperature are the decisive parameters for estimating the life expectancy of printed ink jet media in practical situations.

Introduction

Assuming that fading is a function of time-integrated illuminance, the predicted life-of-display (LOD) of ink jet printed images based on particular accelerated tests often differs strongly from the real LOD. Also lightfastness improvement by protecting the image using UV-blocking laminates is sometimes less than expected.

Next to differences in temperature and humidity between test method and practice, differences in spectral irradiance, weighted by the material's action spectrum[#], and the image optical density affect the accuracy of LOD predictions.

After developing a test method to determine the material's action spectrum, a model study was performed to investigate the influence of the material's action spectrum, the exposure's spectral irradiance, and the laminate's transmittance on the estimated LOD.

The influence of changes in temperature and humidity on life expectancy was evaluated experimentally, and the effect of image optical density was illustrated.

Experimental

Selected Media & Sample Printing

The different ink jet indoor media used were a Coated Paper (med-1), a Cast-Coated Paper (med-2), a Resin-Coated Polymer Blend Paper (med-3), and two Resin-Coated Porous Glossy Papers (med-4 & med-5). Tone scales of primary colours (pure KYMC) having 13 patches with dot areas starting from 0% up to 100% were printed on a 4 colour dyes thermal printer. The printer was linearized for ANSI Status-T optical densities.

Light Fading Tests

Accelerated Xe-arc light fading tests simulating natural sunlight through window glass were performed using a weather-ometer operating according to Standard ASTM G26. The prints were continuously exposed for 60 hours at an UV-irradiance level of 50W/m^2 [300-400]nm, and at four conditions : 25°C/30% RH, 40°C/30% RH, 25°C/65% RH, and 40°C/65% RH. For the examination of the material's action spectrum printed samples covered with optical filters having a cut-off wavelength at 393, 453, 510, 555, 593 and 642 nm respectively, were exposed at 50W/m^2 [300-400]nm, 25°C/30% RH. Figure 1 shows the effect of these filters on the indoor-filtered Xe-arc spectrum. The colour of the printed images was measured before exposure and after every 20 hours of exposure.

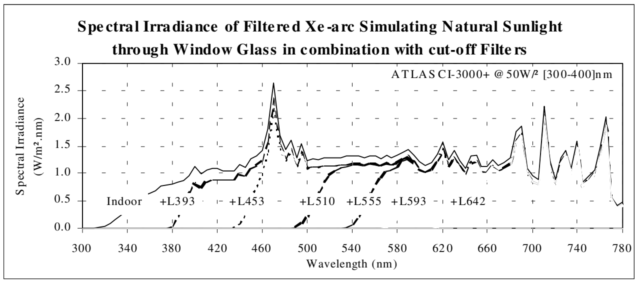

Figure 1. Spectral Irradiance Indoor-Filtered Xe-arc combined with low-wavelength cut-off filters

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[#] The action spectrum of a printed image characterizes the wavelength dependency of colour fading, separately for each primary colour.

Image Colour Measurements

Spectral 45°/0° diffuse reflectance measurements on the printed images with unprinted medium as a reference were performed according to Standard ASTM E1349-90 using a Barbieri Spectro-100xy T/R-spectrophotometer. From the measured spectral diffuse reflectances, the Visual and Status-A reflection optical densities BGR were calculated according to Standard ISO 5-3.

Evaluation Method

Calculation of Fading Constant

The influence of exposure energy on image optical density for the primary colours of printed images at start density 0.3, 0.6, and 1.0 using different filterings was examined. An example for a resin-coated polymer blend paper printed on a thermal printer at start density 0.6 is presented in figure 2.

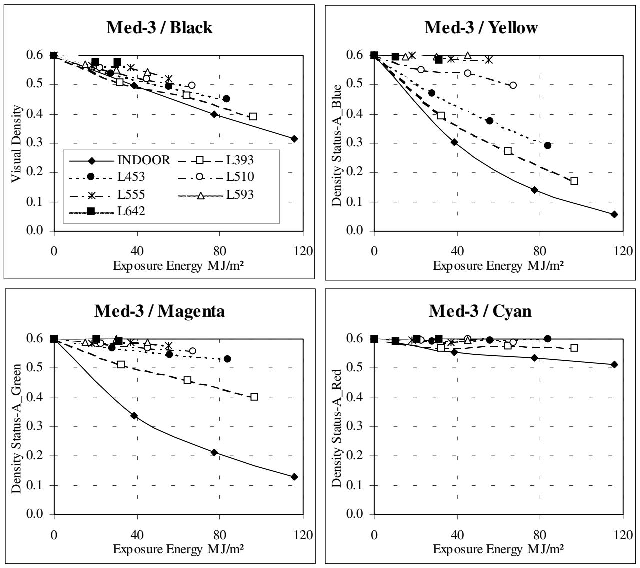

Figure 2. Influence of filtered exposure on image optical density

As expected, it was empirically confirmed that the image optical density as a function of the exposure is best described as an exponential function (equation-1). As defined in equation-2, KF presents the fading constant, being the relative density change per unit of exposure energy, independent of the image start optical density. The exposure energy Q is equal to the time-integrated irradiance E incident on the printed image. The fading constant is expressed in m^2/MJ.

$$D = D_{start} \,.\, e^{-(KF \,.\, Q)}, \text{ wherein } Q=E.t \tag{1}$$

$$(\delta D/D_{start})/\delta Q = -KF \tag{2}$$

Calculation of Action Spectrum

As defined above, the action spectrum of a printed ink jet image characterizes, for each primary colour separately, the wavelength dependency of colour fading. For printed ink jet images having the action spectrum $S_{(\lambda)}$ and being exposed with a radiant source of known spectral irradiant energy Q_λ, the fading constant KF depends on the action spectrum and the spectral irradiant energy following equation-3.

$$KF = [\Sigma(S_{(\lambda)} \,.\, Q_\lambda \,.\, \Delta\lambda)] \,/\, [\Sigma(Q_\lambda \,.\, \Delta\lambda)] \tag{3}$$

From a series of filtered exposures as defined in the experimental part and for each primary colour, one obtains a set of such equations for KF in overlapping wavelength ranges. From these the action spectra $S_{(\lambda)}$ were calculated. The material's action spectrum is expressed in m^2/MJ.

Life-of-Display Calculation

The LOD shall be the time in which a given density change D/D_{start} is reached. Starting from the computed material's action spectra $S_{(\lambda)}$ of the primary image colours and the spectral irradiance E_λ of the exposure source using duty-cycle δ, the LOD was calculated from equation-4 :

$$LOD = -ln(\, D/D_{start}\,) \,/\, \{\delta \,.\, [\Sigma(S_{(\lambda)} \,.\, E_\lambda \,.\, \Delta\lambda)]\} \tag{4}$$

Calculation of Exposure's Acceleration Factor

To predict the practical display life (LOD^{prac}), the display life as estimated from accelerated tests (LOD^{acc}) must be corrected by a so-called Exposure's Acceleration Factor (EAF). Taking into consideration that the images fade reciprocally, the exposure's acceleration factor was calculated using equation-5.

$$EAF= (\delta^{acc}/\delta^{prac}) \,.\, \{[\Sigma(S_{(\lambda)} \,.\, E^{acc}{}_\lambda \,.\, \Delta\lambda)] \,/\, [\Sigma(S_{(\lambda)} \,.\, E^{prac}{}_\lambda \,.\, \Delta\lambda)]\} \tag{5}$$

Calculation of Laminate's Blocking-Effect

A laminating layer introduces a wavelength-dependent attenuation of the exposure. Therefore, the influence of lamination on display life, called the laminate's blocking effect BE (LOD improvement factor), was calculated using equation-6 starting from the laminate's spectral transmittance $T_{(\lambda)}$, the exposure's spectral irradiance E_λ and the material's action spectrum $S_{(\lambda)}$.

$$BE = [\Sigma(S_{(\lambda)} \,.\, E_\lambda \,.\, \Delta\lambda)] \,/\, [\Sigma(S_{(\lambda)} \,.\, E_\lambda \,.\, T_{(\lambda)} \,.\, \Delta\lambda)] \tag{6}$$

The Effect of Temperature & Humidity on Display Life

The relative change of LOD due to changes in temperature and/or humidity was calculated from the fading constants KF_1 and KF_2 computed from the image optical density as a function of the exposure energy at the respective conditions (T_1,RH_1) and (T_2,RH_2) using equation-7.

$$(LOD_2 - LOD_1\,) \,/\, LOD_1 = (KF_1 - KF_2\,) \,/\, KF_2 \tag{7}$$

Results and Discussion

Action Spectrum of Printed Ink Jet Images

The material's action spectra were computed separately for the primary colours starting from the averaged fading constants at start densities 0.3, 0.6 and 1.0, following the above mentioned evaluation method, i.e. exposure with different filterings. Figure 3 shows the action spectrum for the primary colours on the different media printed on the thermal printer. The action spectra show, especially for the yellow and less for the black primary colour, that rather than only UV-irradiation also irradiation in the visual spectrum up to 550 nm contributes substantially to fading. Visual irradiant energy absorbed by yellow and black image parts will bleach these colours. Black and magenta image parts are most sensitive to irradiation below 450 nm. Compared to black, yellow, and magenta, the sensitivity of cyan to UV-irradiation is nearly negligible. The results, independent of the light source, show how the action spectra depend on the media.

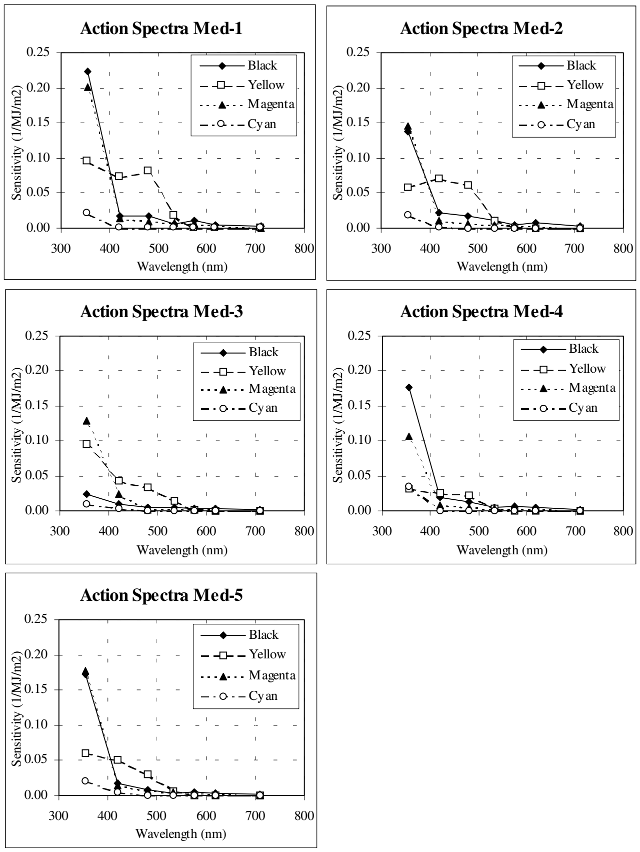

Figure 3. Action Spectra of primary colours printed on different media (thermal printer 4 colour dye inks)

Life-Of-Display Calculated from Action Spectrum

The LOD's calculated separately for the primary colours from equation-4 at 25% density loss under indoor-filtered Xe-arc at 50W/m^2 UV-irradiance [300-400]nm, and starting from the action spectra of the five printed media, are summarized in table 1. The differences between the experimental LOD's evaluated at start densities 0.3, 0.6 and 1.0, and the LOD's calculated from the action spectra were found to be smaller than +/-15%.

Table 1. Calculated LOD (Indoor-filtered Xe-arc @50W/m^2 [300-400]nm)

	Black (K)	**Yellow**	**Magenta**	**Cyan**
	Hours	**Hours**	**Hours**	**Hours**
Med-1	6	5	8	94
Med-2	8	6	11	87
Med-3	26	8	12	126
Med-4	8	16	15	61
Med-5	9	9	9	72

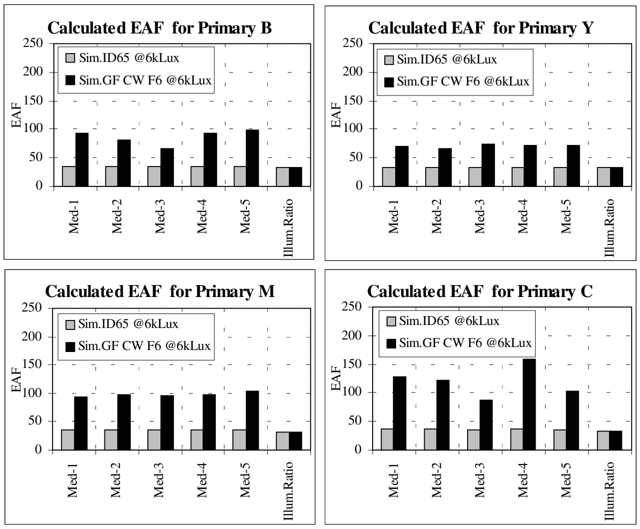

Figure 4. Calculated EAF's of accelerated Indoor-filtered Xe-arc light fading tests

Action Spectrum and Life-Of-Display Prediction

For each primary colour printed on the evaluated media equation-5 was used to calculate the EAF's needed to predict the LOD starting from accelerated indoor-filtered Xe-arc tests (50W/m^2 [300-400]nm). The EAF's, estimated both for indirect daylight through window glass (ISO 18909, ID65 @6kLux, δ=50%) and glass-filtered cool white F6 fluorescent light (ISO 18909, @6kLux, δ=50%) were compared to the conventional light-dose-based correction factors. Because of a good spectral match between indoor-filtered Xe-arc and ID65, the above mentioned EAF's simulating ID65, varying from 32 to 37, are nearly comparable with the light-dose-based acceleration factor being 32. In this case the EAF is slightly dependent on the material's action spectrum. On the other hand, because of a total mismatch between indoor-filtered Xe-arc and Glass-filtered Cool White F6 Fluorescent light the EAF's calculated from equation-5, varying from 66 to 160, differ considerably from the light-dose-based acceleration factor being also 32. Especially in this case the variations in EAF were caused by differences in action spectrum between the printed primary colours.

The following results were obtained for the simulation of glass-filtered cool white F6 fluorescent light (6kLux, δ=50%): the LOD predicted via the action spectrum results in values 2 up to 5 times larger than conventionally calculated from illuminance. In case of simulation of indirect daylight through window glass (6kLux, δ=50%) the LOD predicted via the action spectrum is only 15% higher than conventionally calculated.

The predicted LOD's of the tested media simulating Glass-filtered Cool White F6 fluorescent light @450 Lux instead of 6 kLux, using the proper acceleration factors from figure 7 with a correction for the illuminance ratio (=6000/450), are given in table 2.

Table 2. Predicted LOD (GF CW F6 @450Lux)

	Black (K)	Yellow	Magenta	Cyan
	Months	**Months**	**Months**	**Months**
Med-1	11	6	14	224
Med-2	12	8	20	196
Med-3	32	11	21	205
Med-4	14	22	26	180
Med-5	16	12	18	137

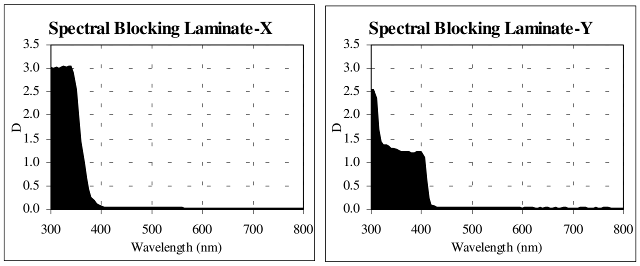

Figure 5. Spectral Absorbance of UV-Protective Laminates

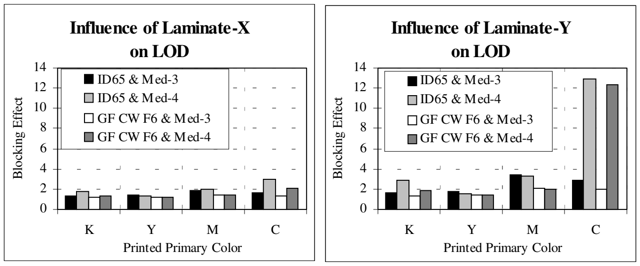

Figure 6. Blocking Effect of UV-Protective Laminates on printed ink jet images

Effect of UV-blocking Laminates on Display Life

For two printed ink jet media, the LOD improvement both under ID65 and GF CW F6 illumination, using two practical UV-protective laminates X & Y having spectral absorbances as given in figure 5, was calculated from equation-6. Figure 6 shows the predicted blocking-effect of both laminates on the two different media printed with primary colours on a thermal printer.

Laminate X with the highest UVA-blocking (1000x) protects the image less from fading (BE in the range of 1.2 up to 2.9) both for ID65 and GF CW F6 illumination because transmission starts from 380 nm, the wavelength range where the image is sensitive to fading. Contrarily to what is to be expected, the laminate Y, which has a 50x higher UVA-transmittance, protects the printed image a little better (BE in the range 1.3 up to 3.5). The better protection of the laminate Y is due to the absorption up to 415 nm. Because CYAN printed on med-4 is insensitive to fading above 410 nm, laminate Y blocks CYAN for about factor 12.

Influence of Temperature & Humidity on Display Life

The relative change in LOD caused by temperature shift from 25°C to 40°C, both at 30% RH and 65% RH, and humidity shift from 30% RH to 65% RH, both at 25°C and 40°C, calculated from equation-7, was summarized in figure 7. It appears from the experiments that the image stability is mainly influenced by humidity changes and less by temperature changes. For the tested images, higher temperatures and humidities may decrease the LOD up to 45% and 70% respectively.

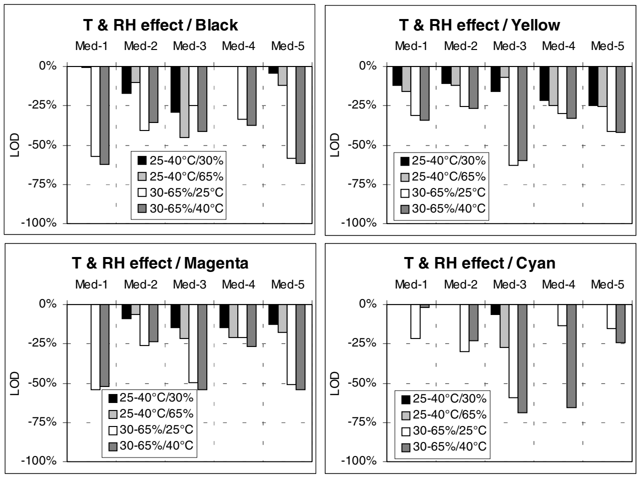

Figure 7. Temperature & Humidity effects on Display Life

Influence of Image Optical Density

The influence of light exposure on relative density changes has shown to be independent of the image optical density. However, because of a non-linear relationship between optical density of different colours and perceived colour, the LOD calculated for a given colour difference

(ΔE_{ab} or ΔE_{94}) depends on the image optical density. Figure 8 shows the colour difference as a function of the image optical density for the primaries on med-3, both in ΔE_{ab} and ΔE_{94}, for 25% of optical density loss.

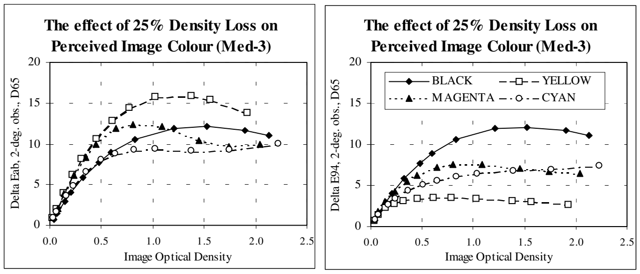

Figure 8. Effect of image optical density on colour difference

Conclusion

The action spectra of printed ink jet media, characterizing the wavelength dependency of colour fading, is quintessential for the prediction of practical display lifetimes based on accelerated light fading tests. Knowlegde of the material's action spectra allows calculation of life-of-display simulating practical exposures having a spectral irradiance distribution different from the one used in the accelerated test methods. Conventional display life predictions, which are merely based on the light dose, can only be performed when the spectral irradiance distribution in the tests matches perfectly to the practical conditions. For a given radiant exposure distribution the effect of laminates on life expectancy of printed media with given action spectra can be studied without any additional light fading test.

This investigation indicates that UV and VIS irradiant exposure energy weighted by the material's action spectrum, and the spectral transmittance of the used laminate, are of primary importance in the calculation of the LOD of printed ink jet media.

Any mismatching between test and practice, with regard to irradiance spectrum, the laminate's transmittance, temperature and humidity can result in an estimated LOD which is the halve or the double of the real LOD in practice. The sensitivity of colour fading to blue and green light explains why UV-blocking laminates do not necessarily improve the lightfastness as much as expected.

In contrast with life expectancies for a relative optical density-change, different for the four primary colours, the LOD as estimated from perceived colour difference depends on the image optical density

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Biography

Guy Van Ackere got a Degree of Engineer Electricity & Electronics at the KIHA Hoboken, Antwerp, Belgium in 1985. The same year he joined Agfa-Gevaert N.V., Belgium, where he started as an assistant project manager in optical measuring methods. Since 1995 he is manager of the department Spectrometry & Colorimetry, recently extended with Weather-Ometry.