Image Engineering printer and print life tests

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Contents

1. INTRODUCTION

The past decade shows a significant increase of digitally produced images by both professionals and consumers. The number of output devices increased and the variety of print materials at different quality levels and with different response to environmental factors more and more substitute traditional silver-halide photography. Comparisons of the technologies become important and show possibilities as well as problems of the new methods.

The need for adequate test methods is the reason why ISO technical committee 42 is currently working on a revision of the Image stability test described in ISO Standard 18909 ('Photography-Processed photographic color films and paper prints- Methods for measuring image stability'). Image Engineering is now participating in the development of the standards which address this issue.

Working drafts at present:

- ISO 18936: Imaging materials- Thermal stability of processed consumer color photographs- Method for testing imaging materials- Thermal
- ISO 18937: Imaging materials- Photographic images- Methods for measuring indoor light stability
- ISO 18940: Imaging materials- Reflection colour prints- Specification for consumer- indoor stability
- ISO 18941: Imaging materials- Gas fading stability of reflection color prints- Method for testing imaging materials- Ozone
- ISO 18944: Imaging materials- Reflection colour photographic prints- Specification for consumer- test print construction and measurement
- ISO 18946: Imaging materials- Reflection colour photographic prints- Method for testing humidity fastness

Our measurements are based on these drafts for upcoming standards and we will try to further improve the methods based on our experience.

When talking about quality and permanence of printed images it is the combination of printing process, paper and colorants that is responsible for the expected lifetime of an image.

The most important digital print technologies for home-printing are inkjet and dye sublimation. In case of dye sub technology heat transfers the colorants from a donor ribbon to the paper while with inkjet liquid inks are delivered to the paper drop by drop.

Two main groups of ink types can be distinguished: dye-based and pigment-based inks. Dye molecules are smaller than pigment particles and soluble and therefore able to diffuse into the paper layer. This makes the print more resistant to scuff and smearing. The advantage of pigment based inks is the higher stability to light and gases like ozone. Dye-based inks produce more vivid and brilliant colors but are less resistant to environmental impacts.

The ink characteristics can vary in combination with different paper types depending on paper coating and layer composition. Special receiver layers enhance interaction with the inks to avoid color to color bleed and lead to better chroma for photo-quality prints. Surface coating and polymer layers protect colorants against degradation caused by light or water.

Due to these characteristics a careful selection of medium and matching ink can provide higher image quality and a longer lifetime.

In general, three main groups of printer or imaging material properties can be determined:

- Permanence
- Image Quality
- Durability

Image permanence addresses environmental factors and how they degrade prints over time. These include temperature and humidity, light with its spectral distribution (parts in the UV) and pollution with aggressive gases like ozone. Accelerated permanence testing is the common method to predict image stability to environmental influences, giving insight on how long prints will last without significant fading in average room conditions.
Experiments have shown that for example prints on microporous papers with dye-based inks can be very vulnerable to pollution especially when displayed unframed and suffer from rapid image deterioration.

Image quality is the more perceptive aspect such as the ability to produce specific colors (large color gamut), fine detailed structure (high resolution) and the uniformity of the print result. The larger surface of pigment particles for example lead to light scattering which decreases color saturation, but progress is going on. Improvements have been made by using more inks like light magenta or light cyan and variable drop sizes to increase the tonal content and the details reproduced in a print.

Durability means resistance against damages caused by all kinds of impacts in every day handling that occur from the moment the sample leaves the printer. For example scratches and fingerprints as well as damages caused by water and smearing are mainly dependent on ink type and paper coating. Pigment based ink prints are more vulnerable to scratches and scuff because the colorant is located on the surface of the receiving layer.

Any of the mentioned criteria in this white paper – no matter whether it is quality or permanence related - can be ordered and measured separately. For the permanence certificate mentioned in 3 however the indoor light fading and the gas fading test are mandatory.

2. PERMANENCE

The lifetime of a print depends on a number of different aspects.
On the one hand the termination of a print can be caused by deterioration of the paper and its coatings on the other hand the colorants of the print may fade or shift their position. Although it will never be possible to simulate all aspects in an accelerated testing the mayor aspects which cause the fading of colorants can be tested. These aspects are "Light Fading" and "Gas Fading" and we have set up test chambers to simulate the fading in an accelerated test as currently discussed by the ISO TC42 WG05 group.

2.1 Light fading

The stability of printed images when exposed to light varies depending on the printing process, the specific colorants, and the paper characteristics.
When a print is exposed to light the energy of the absorbed light destroys the colorants. We test the behavior of a certain process/paper/ink combination in terms of light fading by using an accelerated light fading test. Test samples are exposed to a high intensity light source to simulate accelerated aging. This is possible because most printing processes follow the reciprocity law. Which means that doubling the light intensity results in half the lifetime. There may be printing processes which do not follow the reciprocity law which can be tests performing a low intensity test parallel to the accelerated one. If this is the case an accelerated testing may not be possible.
Since the light-induced fading depends on the spectral energy distribution of the light source the test method should use an illuminant that matches the actual-use conditions as closely as possible. In the 'Survey of environmental conditions relative to display of photographs in consumer homes', D.E. Burger et al., (Eastman Kodak Company) have studied the spectral distribution of indoor light.
In the past most test labs including the Image Permanence Institute at the Rochester Institute of Technology and Wilhelm-Imaging Research used cool white fluorescent tubes to simulate the spectral illumination of the prints in a typical environment but the UV and blue content of these tubes is significantly lower than the one of indoor light which leads to lifetime measurements which are significantly higher than the ones measured with light sources that show a better match to the typical indoor light.
Specially UV-filtered xenon lamps (SC37 filter), match the window-filtered daylight pretty well but these light sources are not easy to handle and lead to significant running costs. Our search for alternative light sources lead to high-efficiency, discharge lamps produced by Philips (CDM-TD 150W/942). The spectral distribution is as close to the daylight as the filtered Xenon lamps but it provides much less IR radiation which is unimportant for the permanence tests but leads to lower costs for air conditioning. Another big advantage in using the discharge lamps is the lifetime of 6000 hours and the efficiency which is with app. 70% close to the one of fluorescent tubes. Therefore it requires much less energy than the Xenon test.

The green curve in Figure 1 shows the spectral distribution of the illuminants we use in our test lab.

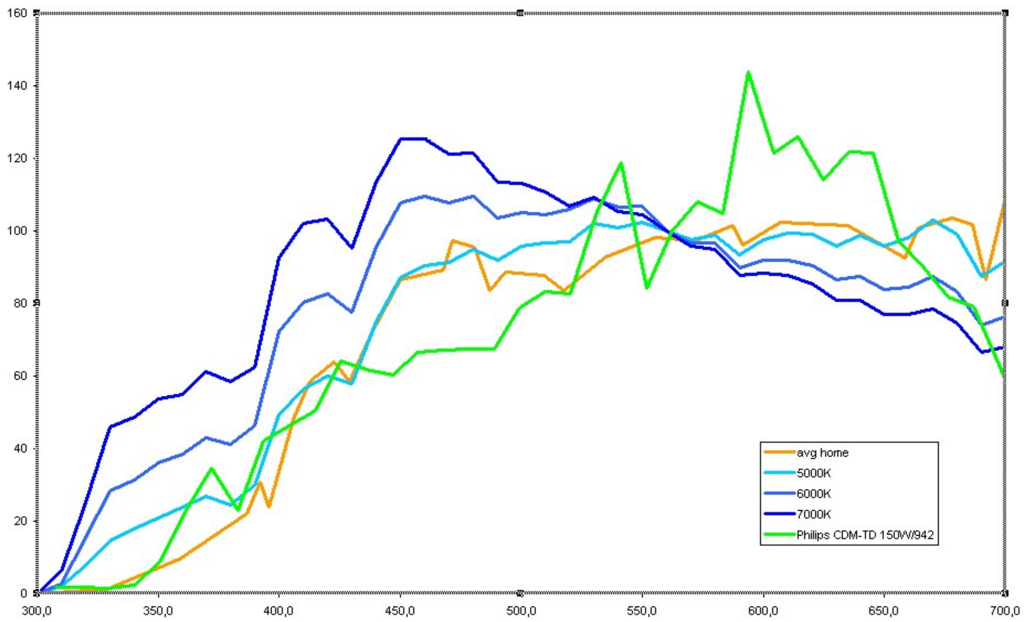

Figure 1: Comparison of different spectral distributions

The light fading unit consists of 25 devices, each with 150 W output arranged in an array of 5 by 5 and surrounded by aluminum plates to achieve a uniform illuminance. See figure2:

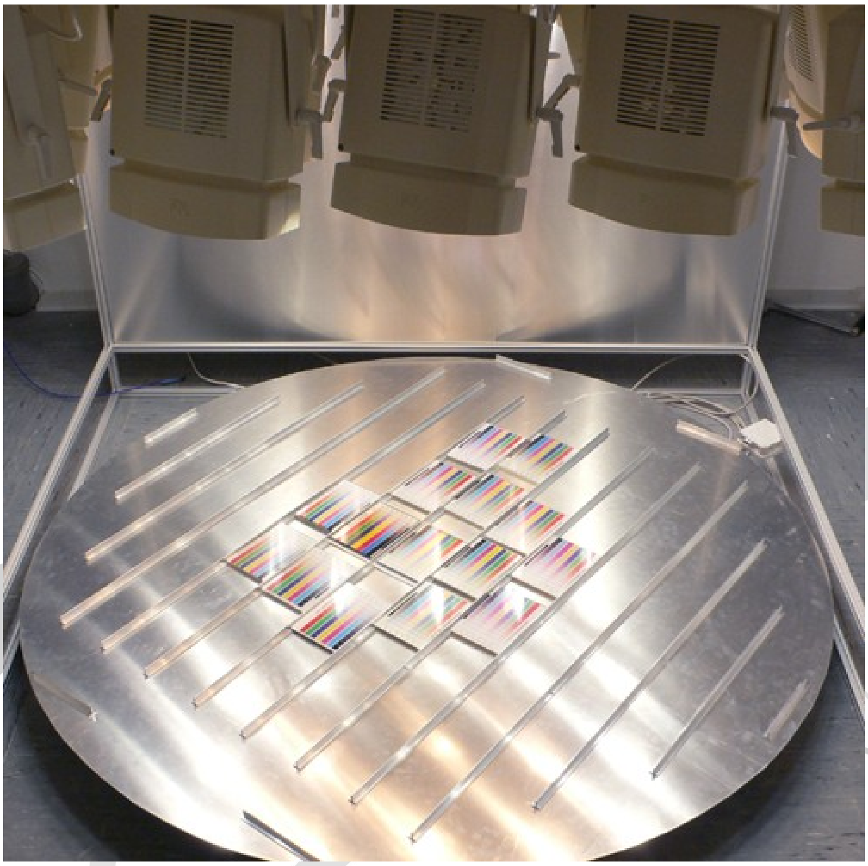

Figure 2: Image Engineering's light fading test chamber

The Prints are illuminated at a level of at least 50 Klux at specified temperature and humidity (23°C and 50% RH).
The test target described in ISO 18944 consists of different color patches, cyan, magenta, yellow, black, red, green and blue in different density steps. The target shall be kept for two weeks at 23 °C and 50% RH before the test starts. Starting densities for the measurement are 0.5, 1.0 and 1.5 of each color (CMY, RGB and Grey scale). Density measurements are performed at defined intervals to evaluate the degradation caused by the irradiation. The tests run until one of the finishing criteria listed below is reached.

No.	Change Parameter	Allowed Change in Status A Densities (at starting point densities of 0.5, 1.0 and 1.5)
1	loss of cyan (red density) in neutral color patches	25%
2	loss of magenta (green density) in neutral color patches	25%
3	loss of yellow (blue density) in neutral color patches	30%
4	loss of cyan (red density) in pure color patches	30%
5	loss of magenta (green density) in pure color patches	30%
6	loss of yellow (blue density) in pure color patches	35%
7	cyan-magenta color imbalance in neutral patches	15%
8	cyan-yellow color imbalance in neutral patches	15%
9	magenta-yellow color imbalance in neutral patches	15%
10	Changes in D_{min}(R), D_{min}(G), D_{min}(B)	0,1
11	Changes in Colour balance d_{min}(R-G), d_{min}(R-B), d_{min}(G-B)	0,06

Table 1: These criteria are matter to change because they are based on the ones used in ISO 18909:2006

but were slightly modified. The future standard may define different densities or colour distances (Delta Es).

These results lead to a calculated life time in terms of light fading without a significant loss of color. Exposure time and intensity are used to derive time predictions for average indoor room conditions (450 lux illumination per 12-hour day, 23°C and 50% RH). See following equation for calculation:

$$Light-Stability_{Indoor}[Years]=\frac{AcceleratedExposure[klux-h]}{0{,}450[klux]*12[h/day]*365[days/year]} \quad (2.1)$$

2.2 Gas fading

Besides the exposition to light there are other aspects which cause the destruction of colorants. Especially the pollution of the air with aggressive gases and in particular ozone causes the problem of fading images. Advancements in ozone resistance have been made, but in general dye-based inks on porous paper are less resistant than pigment-based inks. When displayed the stability of colorants behind glass is much better than without protection due to the exposition to gases.
To make lifetime-predictions for the gas fading of a certain paper / ink combination accelerated test methods can be used as well. Within a test chamber high ozone concentrations can be produced in a closed loop system by UV radiation from a UV lamp. Our Hampden 903 test Chamber can produce concentrations of up to 20 ppm. For the accelerated fading test the maximum concentration we use is 5 ppm. During the test the temperature is kept at 23 °C and 50% RH inside the chamber which is important because especially the humidity has an impact on the fading caused by ozone.

Figure 3: Hampden ozone test chamber

The samples are exposed to different concentrations of ozone without protection of glass and in absence of light. The test is finished as soon as one of the stop criteria listed in table 1 is reached. Density Changes in the color patches of the test target are measured regularly. The lifetime in terms of gas fading is measured by using the formula:

$$Ozone-Stability_{Indoor}[years]=\frac{AcceleratedExposure[ppm-h]}{40[ppm-h/year]} \quad (2.2)$$

Since the ozone concentration varies depending on time and geographical position a typical exposure level of 40 ppm-h per year is set as nominal indoor concentration as base for the calculation.

2.3. Thermal stability

Increased temperature causes changes in density as well as hue. One effect may be smearing and color-to-color bleed of colorants. Long-term stability is evaluated by an accelerated test series. Fading is tested for four different temperatures (range min. 20 °C) with equal intervals, e.g. 55, 65,75,85 °C at 50% RH.

For estimated life-expectancy Arrhenius analysis is used.
This test can not be applied to thermal dye diffusion (dye sublimation) devices due to the technical properties. Density changes because of colorant migration cannot be correlated to colorant degradation. The only conclusion can be derived from change in minimum density of the print material.

2.4. Humidity fastness

High temperature and high humidity can lead to loss of sharpness and color balance depending on paper and ink type. Particularly inkjet prints on swellable paper printed with dye-based inks suffer from higher humidity. Prints made with pigment-based inks are usually less sensitive to high temperature and humidity.
To test the stability of the print result at higher humidity it is kept at 30°C and 80 %RH for a time of 4-14 days. Color shift (Delta E) can be measured with a spectral photometer in color and neutral patches as well as in flesh tones.

3. PERMANENCE CERTIFICATE

Due to the problems of image permanence with some ink/paper combinations the Customers are asking for a lifetime of an image usually stated in years.

For prints behind glass mounted on a wall these numbers can be measured using our light fading test described under 2.1 and calculated with the related formula 2.1. Especially inkjet prints which are not covered with glass are usually faster destroyed by gas than by light. In this case the gas fading is more relevant.

An ink/paper combination has at least to pass the gas fading and light fading test to receive a permanence certificate from Image Engineering.

The permanence certificate states two lifetimes:

1. The lifetime given for “indoor light fastness” states the result of the indoor light fading test only and can be applied to prints behind glass which are exposed to extreme temperatures and humidities.
2. The lifetime reported for “Ozone fastness” is calculated based on the color changes caused by the ozone fading at room temperature and 50% r.h. In this case the prints are not exposed to light.

Permanence Certificate		IE
Colorant	Sample Ink	
Media	Sample Paper	**Image Engineering**
	Indoor Light Fastness	**Indoor Ozone Fastness**
Lifetime	**x Years**	**y Years**
A detailed report, test criteria, and the lifetimes of reference colorants/media can be found at www.image-engineering.de.		

In real life the prints are typically exposed to a combination of light and ozone which can not be predicted. Therefore the values are measured and reported independently.

Although the test conditions are kept constant and have been chosen very carefully to represent a typical situation for an indoor image they can not represent all conditions under which images are displayed and stored. Therefore the lifetime of an individual print can not be guaranteed and may differ from the reported values.
Most of the independent test labs currently use cool white fluorescent lamps. The spectral distribution of this light source does not correspond to the typical indoor distribution. Several tests have shown that for most materials the lifetimes measured with cool white fluorescent lamps are app. two times higher compared to the ones measured with a source representing the typical indoor light like our source or xenon lamps.

4. IMAGE QUALITY

4.1. Color gamut

Each combination of printer, paper and ink leads to a different color gamut. To detect the printer's reproducible colors a test form with RGB or CMYK color patches is printed and measured with a spectral photometer. From this data an ICC-Profile is derived which is used for gamut analysis and display and color management purposes.

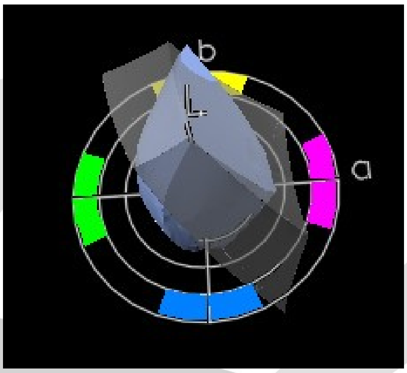

Figure 4: sRGB working space (gray) vs HP Designjet2100 with Hahnemuehle FA Paper (blue)

4.2. Maximum density

One little but often discussed aspect of image quality is the maximum achievable density in the shadows of an image which varies depending on the combination of printer, paper, and ink. A black patch of a test form that is printed by the printer driver is measured with a densitometer in status A mode and reported.

4.3. Uniformity in color patches

Sometimes printed color patches or uniform areas in an image are not printed uniform. This may be caused by plugged or disaligned nozzles of the printhead or distance invariances of printhead and media etc.. To check whether a printer shows this problem or not big color patches are printed and judged visually.

4.4. Resolution

An important characteristic of a printer/paper is the possible print resolution which has impact on the behavior in detailed structure. To determine the maximum resolution of the device not only by visual evaluation a special test method for testing resolution of digital cameras is adopted. A sine modulated Siemens star test form is printed and digitalized by a high resolution camera.

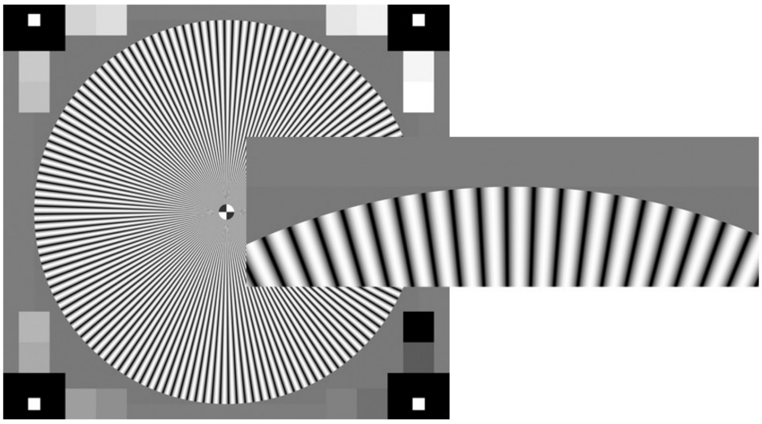

Figure 5: Detailed view shows the modulation of the siemens star

The captured image is evaluated using a special analysis software and an excel spreadsheet. The result shows MTF curves (contrast over frequencies) from which the resolution is determined reporting the frequency where a 10% contrast is reached.
(for detailed description of the test method see also 'Modulated siemens star method to determine the resolution of digital camera systems', available at www.image-engineering.de)

4.5. Coalescence/ over printing

Problems in paper-ink compound may lead to defects in print results, in particular at edges. This can be determined by printing a test form with different colored letters on different colored patches. Visual analysis shows coalescence and colorant bleed of inks from color to color at sharp edges.

4.6. Visual appearance

Visual analysis of text printed in different sizes provides information about resolution and sharpness at sharp edges.

Average consumer images like portraits, landscapes, or pictures with color dominance or containing high contrast are printed for visual evaluation. In addition color gradients should not contain visual steps. Test criteria are visibility of dots in uniform areas, details in structured areas, quality of halftoning, color reproduction quality.

5. DURABILITY

5.1. Water resistance

An important property of color prints is the behavior when the print is exposed to water. The degree of resistance depends on the ink or colorants in combination with the print media and its coating.
ISO 18935 mentions three categories for water fastness: water resistant, moderately water resistant or not water resistant. Three different test methods are used to categorize the different prints: standing water evaporation, standing water plus wiping effects and water soak. We adopted three additional test methods mentioned in a test description of Hewlett Packard. All methods are listed below.

Waterproof and Water Resistant Tests			
Type	Description	Waterproof	Water resistant
Immersion	Test print is immersed in water for one hour.	Must Pass	not required
Standing Water Drop Evaporation	Water is placed on test image and allowed to stand for 24 hours. If waterproof, there will be no damage.	Must Pass	not required
Standing Water Blotted Off	Water is placed on level test print. After one minute, water is wiped off using a weighted cotton cloth.	Must Pass	Must Pass
Spray	Using a Standard household spray bottle, water is sprayed on flat-positioned test print. Water is allowed to evaporate for 24 hours.	Must Pass	Must Pass
Water Drip (inclined)	Water is dropped on a test print held at a 45 degree angle.	Must Pass	Must Pass
Wet Smudge	Water is dropped on a test print held at a 45 degree angle and wiped off with a weighted cotton cloth.	Must Pass	Must Pass
Test samples are printed 24 hours prior to testing			

Figure 6: Table of water resistance and waterproof tests

5.2. Surface, scratch and scuff resistance, fingerprints

To simulate everyday handling of the prints a test print is cut in pieces and shuffled. Damages such as scratches on the surface can be detected visually.
Perceptibility of fingerprints is tested after different drying times (short time of 2-5 minutes and longer drying time of >24 h). Several test persons are asked to press a finger on a black and on colored patches to simulate an 'average' fingerprint on the paper. After that we try to wipe visible fingerprints away.

Possible damages caused by the mechanical paper transportation in the printer are visually evaluated.