Accuracy in Photo Print Life Prediction

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Abstract

Although the methodology for developing life predictions has been in use for some years in the industry, it is becoming clear that the implied precision in the use of a single value in years cannot be scientifically supported due to much variability between the measurement of an assumed exposure and the actual exposure and observation conditions. All print life predictions assume that the print is exposed to only one condition for its complete life. That is, a light fade prediction assumes no ozone exposure (or exposure to any other industrial gases), and no effects from high or low humidity. Obviously such assumptions are likely to be invalid in almost all real life exposure situations and the data for the long term effects of combined exposures is scant to say the least. This paper examines the implications of this on real life print exposure.

Introduction

Concerns about the long term stability of color photographs have been expressed for at least 30 years, beginning with museums and galleries. With the advent of low cost high quality digital imaging systems, the printing industry developed an awareness of the problem and took steps to formulate inks and media that would insure long term stability for prints made using the new processes. During the same period, suppliers of analog media also made significant improvements. Today long lasting photographic prints may be made using inkjet, silver halide, thermal dye transfer, and both dry and wet electrophotographic technologies. Some prints will still last longer than others, and since stability is measured in many decades the industry uses predictive models to compare relative performance. Methodologies for predicting the permanence of photographic images based on accelerated aging testing are now matured to the point of general acceptance in the industry in spite of the fact that there are still few standards that define these methodologies.

Storage and Display Issues

As noted, the first users to be concerned with image permanence were museums and galleries where prints would be exposed to relatively high light levels as well as relatively high levels of contaminated air found in large cities. These conditions remain the most damaging for photographic images. Most museums and galleries today control the light levels, spectral content, temperature and humidity and even ozone in ways designed to minimize the harmful effects. The main target for image permanence ratings is more likely to be the consumer than these establishments. Consumer photo storage falls into two main categories, display and shoebox. The display category represents a relatively small proportion of all printed photo images. Most images are kept in dark storage of some kind, including photo albums and ‘shoeboxes’. It has been shown that photos kept in dark storage or in albums generally have a significantly longer life than those that are on display.

While current predictive methods are relevant for museums and for some consumers, there is generally no attempt to explain or even predict to the consumer the difference in image stability of dark storage conditions that prevail for the vast majority of prints.

Finally, even for wall hung prints, we have the issue of open or glass covered, and the use of lacquers to provide protective finishes for photographs. Each of these has been shown to have a significant effect upon the fade life of the photo[i].

Real World Exposure Conditions

The marketing of image permanence predictions is based on test methods that are intended to emulate the display environment, especially for consumers. It is therefore necessary to know the parameters of the display environment in terms of the factors likely to affect image stability. A number of studies have shown that the most important factors are light, pollutants, temperature and humidity. In general, image permanence predictions are based on extrapolating the results of testing that exposes images to high levels of one or more of these factors, the most commonly reported being light and ozone.

In order to understand the accuracy of permanence predictions it is first necessary to determine how the predictions correlate to actual exposure. Previous studies have established the average exposure conditions for wall hung photo displays in homes around the world. Exposure to light, ozone, temperature and humidity has been measured and the following is a summary of those findings:

Measured Light Levels

There have been several reports based on anecdotal measurements[ii][iii], but the largest test based on worldwide measurements was reported in 2004 and 2006[iv]. This paper reported measurements of light, temperature and humidity for wall hung photos in eight homes in each of two cities (Shanghai and Atlanta), and consolidated this with earlier measurements made in eight homes in each of four additional cities (London, Rochester, Los Angeles and Melbourne). Data were collected throughout the day and night for several months encompassing changing seasons. The mean and maximum measurements are as shown in Table 1.

City	Mean (lux)	90th Percentile (lux	95th Percentile (lux)	99th Percentile (lux)
Rochester	62	151	218	431
Los Angeles	71.5	140	177	312
Atlanta	19.6	46.1	66.9	109
London	76.1	151	208	964
Melbourne	93.7	211	343	617
Shanghai	59.1	156	227	469

Table 1. Daytime Light Levels for Homes in Cities

The report analyzed the average exposures and concluded that 136 lux represented the 90^{th} percentile, 211 lux the 95^{th} percentile and 540 lux the 99^{th} percentile of the readings. The report also summarized the average measurements for each location in a histogram as depicted in Figure 1.

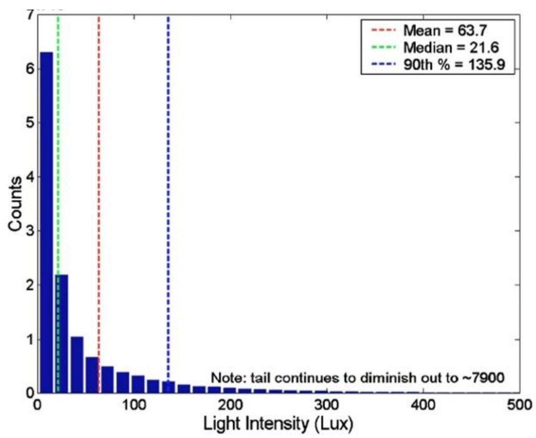

Figure 1 - Daytime Light Levels

From these data it is obvious that there is a wide variation in light levels even in the continental United States where a range of more than 3:1 was found between locations depending upon the percentile examined. This study also analyzed the spectral distribution of the light measurements and concluded that consumer display photographs are dominated by window (or glass) filtered daylight. Further, 47 of the 48 locations studied had an average daytime light level that was less than 200 lux.

Measured Ozone Levels

Government agencies monitor ground level ozone around the world and there is abundant data for outside levels. The US Environmental Protection Agency monitors and reports ozone levels in US cities[v]. The most recent data for selected cities is summarized in Table 2.

City	2006 Outdoor Mean Levels ppb	2006 Est. Indoor* No A/C - Convection Exchange	With A/C
Atlanta, GA	51	21	16
Houston, TX	49	20	16
Los Angeles, CA	37	15	12
New York, NY	42	17	13
Salt Lake City, UT	57	23	18
San Jose, CA	37	15	12

Table 2. Ozone Levels in ppb in US Cities

The photos we are concerned with hang indoors. The ozone levels reported for outdoor exposure are measured, while the EPA reported values for indoor exposure are calculated based on models developed for art museums[vi]. All values are mean, larger variations will inevitably be measured in individual instances and if 90^{th} to 99^{th} percentile examples are to be taken into account.

Even based on the mean measurements in US cities, there is a range of exposure of about 2:1. Other studies that have related outdoor to indoor ozone levels have shown a more variable factor between outdoor and indoor levels of ozone[vii]. Summary results of this analysis for homes in Southern California are listed in Table 3.

	Locations	Ozone Level ppb Median	90th Percentile	95th percentile
Indoor	106	11.1	34.2	41
Outdoor	100	49.8	89.6	95.7

Table 3 - Ozone Levels in homes in Southern California 2001

The European Environment Agency monitors ozone levels in Europe and publishes an annual summary of findings[viii]. The Agency reports incidents that exceed outdoor thresholds for at least one hour rather than absolute levels of ozone. In summary, there were 190 incidents where levels exceeded 240 ppb and 56% of almost 2,000 measuring stations reported incidents where the ozone level exceeded 180 ppb for one hour. Without having detailed measurement data including average readings we cannot provide statistical analysis. However, it is likely that average European levels are at least as high as those listed in Table 3.

In a recent study[ix] it was reported that the location of a photo within the house also affected the level of ozone exposure. Photos that were subject to frequent outdoor air exchanges such as entrance ways experienced an average of 3 times the ozone exposure when compared to normal indoor locations. A more comprehensive worldwide study[x] reported similar levels of ozone in cities around the world taken in summer and winter. This study recommended that indoor ozone levels should be assumed to average 10ppb. It should be noted that this study did not take air conditioning into account and appears to be at variance with government reported ozone levels.

Testing Methods

Methodologies for testing the permanence of photographic images based on accelerated aging testing[xi] have matured to the point of general acceptance in the industry although there is still no standard issued and variations are found.

Light Fade Test

Most test facilities report exposing samples to a high light level, usually 35 or 50kLux, for a relatively short period. Some test facilities use xenon lamps for exposure and some use daylight fluorescent tubes. During exposure the ambient environment is held at about 23 ˚C and 50 or 60%RH. Generally ozone is filtered from the air in the test facility and ozone levels are monitored to insure that ambient ozone does not exceed 3 parts per billion (ppb). Most test facilities make it clear that they monitor temperature and humidity at the image plane. Some place a glass filter between the lamps and the images, and some use a polycarbonate filter. The use of a polycarbonate filter is being phased out as better understanding of the effects of the UV component in the radiation is developed.

These test conditions reflect the fact that various display factors can affect the print life. Glass and polycarbonate both filter

UV light which is a strong contributor to fade. Temperature and humidity[xii] may also affect the rate at which prints fade.

There has been some evidence of reciprocity failure in light fade testing of inkjet photos[xiii]. Reciprocity effects are likely to be different for different ink and media combinations.

Ozone Test

The methodology for testing images for exposure to ozone is also generally accepted[xiv]. Sample prints similar to those used for light exposure are hung in a commercially available ozone test chamber. Air with added ozone is circulated through the enclosed chamber. Temperature, humidity and ozone concentration are controlled, typically at 23 ºC 50% RH and 1 part per million (ppm) or 5 ppm of ozone. Most chambers use a UV lamp as an ozone generator. Most test facilities exclude ambient light during the test so that the test isolates the effect of ozone.

There is however evidence that accelerated testing at a single ozone concentration is not a sufficient basis for predicting the long term effects of exposure to low ozone concentrations[xv].

Endpoints

For light fade and ozone tests samples are typically printed as a series of color patches designed to provide test points throughout the color gamut of the printer. Each color patch is measured before exposure and at intervals during the exposure and again after the test is concluded. Calibrated spectrophotometers are used to measure density of the patches.

Print life is predicted in years to failure. Failure can be described as either a ‘just unacceptable’ level of fade or as a ‘just noticeable’ level of fade. The current standard reference[xvi] chooses a value change of 0.3 density units from one or more defined initial densities as a just unacceptable level of fade and this is the endpoint for the test. The measurement may be an additive or subtractive primary measurement. Although colorimetric values are acknowledged to relate user perception of print stability better than densitometric values[xvii], the latter are currently used exclusively when reporting stability data.

Prediction Methods

The methods used to extrapolate testing data for light and ozone fade into predicted print life are used by all test labs.

Light Fade Prediction

The simplest way to use the accelerated test data to predict the stability of prints over a much longer time is to divide the total kLux hours of exposure to reach the endpoint by the assumed ‘normal’ exposure of the print on a wall. A key factor in this calculation is ‘what constitutes normal?’ There are no standards to guide this, and the most common current default is the WIR assumption of 450 lux for 12 hours per day. Based on the data shown in Figure 1 and the supporting data in the referenced paper, this represents the 99th percentile of daylight exposure to be found in homes around the world. Using this assumption, if a photo print reached an endpoint after being exposed to 35 kLux for 100 days, the prediction would be as follows:

Predicted Life = (35000 x 100)/(450/2)/365 = 42.6 years

Such predictions are generally provided in this form, that is, whole number of years or to the first decimal point. The implication is that the testing and calculations support a precision level that can be relied upon.

Ozone Fade Prediction

The calculation for the prediction of print life based on ozone exposure follows the same method as that for light fade. In this case, the key factor is ‘what constitutes normal ozone exposure?’. Once again there are no standards to guide this assumption. Most published predictions assume a normal ozone exposure of 5 parts per billion. Based on the data provided by the US EPA and listed in Table 2, this represents perhaps the 75th percentile for indoor exposure in the US. Using the extrapolation method that we had above, and assuming a 1ppm ozone test that reached an endpoint at 100 days, we would have:

Predicted Life = (1000 x 100)/(5)/365 = 54.8 years

A recent report[xviii] that summarizes proposals for an ISO standard for image permanence testing exposure and life predictions indicates that the proposed ISO standard will use 9ppb as representing the 95th percentile exposure level for homes around the world.

Scientific Inaccuracies in Predictions

We have reviewed the data, the test methodology and the prediction procedures for assessing the acceptable image stability of photo prints. We will now provide an assessment of the accuracy of the outcome of these procedures.

Endpoint Issues

Current methodology defines the endpoint as a just unacceptable change in reflected density of any of the primary colors. A study[xix] showed that this criterion is inadequate and significantly underpredicts what psychophysical analysis finds to be unacceptable. The extent of this underprediction is not well characterized and needs further analysis. Since prints fade at different rates depending upon the chemistry, it is not likely that changing the endpoint to a more realistic measure will result in a uniform change to predicted image life. An additional study based on psychophysical factors also concluded that some current endpoint criteria understate the failure point and some overstate[xx]. That study recommended specific changes to improve accuracy.

Inaccuracy Due to Real World Variations

The real world light fade data was presented in an effort to show that it is extremely inadvisable to present a single predicted image life in years based on accelerated light fade testing. It is clear from the data that homes in different parts of the world can have exposures that vary from one to another by as much as 3:1. Based on our understanding of statistics and the relatively small sample database, it is likely that this range of exposures represents only a fraction of the actual range. However, if we assumed that the calculated prediction given in the example was a 98th percentile, then some users would have acceptable prints for more than120 years. In fact an anecdotal measurement in a single home in Rochester, taken in all photo locations in January and June showed a range of exposure of more than 3:1. We could tell the consumer to move a photo from one wall to another and predict that the life would go from 46 years to 120!

It has also been reported that variation of humidity on samples during exposure to accelerated light fade can significantly affect the endpoint[xxi]. In this test, variations of as little as 10% RH had significant effects upon the changes in some of the colorants.

When we look at ozone exposure we see even greater potential inaccuracies in reports of predicted life. Analyzing the data from government measurements and corporate reports, we see that the probable range of average exposures indoors to the 95th percentile may be from 10 to 41 ppb. So if we repeat the example above but for both of these exposure levels, we would have a range of life from 25 to 7 years. This is a long way from 55 years.

Inconsistency Between Light and Ozone Assumptions

By now it should be obvious that the criteria for selecting 'normal' exposure for light fade and for ozone are quite different. The usual selection of 450 lux for light fade represents the average exposure level for about the 98th percentile of measured locations. The usual selection of 5ppb for ozone fade represents less that the 80th percentile based on the data presented. From these data this variance is scientifically unsupportable.

It should be noted here that there may be an unintentional media bias in these selections (no, not that kind of media bias). Thermal dye transfer and silver halide prints tend to be highly resistant to ozone fade but more susceptible to light fade than inkjet prints. Inkjet however is more susceptible to ozone fade than either of these other processes.

Assumption of Pollutant Stability

It is known that industrial pollution has changed the level of atmospheric pollutants to varying degrees around the world and we have noted some of those variations. Levels of pollutants such as ozone, nitrous oxide and sulphur dioxide have risen quite quickly over the past 20 years. In some cases there are reasonable hypotheses that connect these levels to industrial emissions but in some cases the connection is more difficult to establish. A recent report[xxii] predicted that average outdoor surface ozone would increase from 35ppb to 60ppb and atmospheric sulphur dioxide by a factor of 4 in the 25 years from 2005 to 2030 for example. When we make life predictions of 100 years or so for image stability, we assume that these levels will not change. This is clearly scientifically unsupportable.

Neglected Factors

There are a number of other factors that affect the accuracy of photo print life prediction. The most obvious is the so-called shoebox storage. It has been shown that photos that are kept in an album, box etc where the light and ozone exposure is minimal and the temperature and humidity is at or near normal will have very long life. This is of course the predominant storage method for photo prints today.

As noted above, the issue of reciprocity failure is not fully resolved. Certainly there is evidence that accelerated ozone testing cannot always be relied upon to provide straight line extrapolations for life predictions especially if the chamber conditions are not standardized[xxiii].

Ozone is not the only pollutant gas that has been shown to cause instability in printed images[10]. Other gases that are present and have been shown to cause deterioration of images include nitrous oxide, yet the effects of this gas are neither measured nor widely reported.

We have not included the effect of color bleed on a consumer's perception of acceptability. Color bleed in thermal dye transfer can occur due to extreme temperature fluctuations (above 50 degrees C) and can occur due to humidity effects in some inkjet prints. It has been reported that color to color bleed effects as small as 50 microns can affect the acceptability of a photo[xxiv]. There is no standard for color bleed and no life predictions are generally given, but it is yet another factor that bears on the likely acceptable display life.

A factor that is usually overlooked is the potential for synergy in the combined effects of light exposure and ozone exposure. A recent study reported a humidity dependence on ozone life predictions and a synergy between light and ozone exposure, providing reduced life on swellable media[xxv]. Other, less significant issues may arise when we examine the consistency between test labs in their procedures, instrument calibrations etc. There are also likely differences in light fade measurements between the spectral distribution of the test source vs the actual spectral distribution in the user environment[xxvi].

Scientific Prediction

This survey has admittedly been brief and the analysis has focused on light and ozone fade only, but we believe that the conclusions are clear. It is always tempting but dangerous to predict the future. Scientists are better off reporting what they actually did than what they think it might mean. Some labs do report both light fade and ozone fade life predictions in the same table, and while this practice is to be commended, we believe that it still does not present a scientifically accurate assessment of real world photo life.

In image permanence testing, what we actually measure is the relative resistance to fade under high exposure levels of various single controlled factors. These factors have been shown to vary widely from location to location, yet the consumer is not likely to understand this variation when a single prediction of life in years is provided, even if a note is appended that 'your results may vary'.

This report argues that real life image stability cannot be predicted for a single factor without reference to other factors. The report also lists evidence that the measured failure criteria are unlikely to represent what most consumers would accept as failure criteria. It further argues that the variation in environmental factors is so large that the public is being misled when a single predicted life in years is provided. It should also be noted that if we want to predict life in years and then inform the public of all of the possible caveats and variances that are incorporated in this prediction, there is not enough room on a printer box, and there is not enough interest on the part of the consumer to read all of this information.

In order to be constructive, we strongly recommend that the industry stop making life predictions in years and move to a rating system that assesses resistance to fade on a relative scale.

Author Biography

Peter Mason has more than 30 years experience in the development of digital printers including many years at Xerox Corporation. He was directly responsible for the first commercial laser printer, and holds several basic patents in the field. His later experience covers product development in commercial and industrial powder and inkjet technologies including consumer products. As Chief Technologist at TPR he maintains a close awareness of new products and technologies and their potential applications.

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