Lightfast Ink Jet Images

David J. Matz, DuPont Ink Jet Inks, Wilmington, DE

1. Abstract

Will ink jet prints made with your products meet the print buyer's needs? With great image quality and competitive price, they will meet immediate needs. But only if the ink and media were chosen to match the customer's image display conditions will the image stay high in quality as long as the customer expects.

Ink jet printing is a system. To get high quality images that last as long as customers want, you must match ink, media, printhead, printer, software operation and settings, posttreatment material and processes, and display conditions. To project ink lifetimes you must know the ink and media, and must understand how to project to real conditions from the lifetime reported at standard conditions.

Early ink jet dye inks had short lifetimes – even under dim lighting. Recent dye inks have extended lifetimes – but only under limited display conditions. Under real world conditions, a sizeable percentage of dye images will fade much sooner than the customer expects. Will these new inks meet customer expectations or will they disappoint so many customers that it will hurt business?

Pigment inks will last years outdoors and generations indoors; but can you get the printer reliability, color gamut, and image quality needed for quality images? Pigment inks in the right system give a robust printing process that produces high quality images with all the color saturation that customers require. These inks are as lightfast as the paints used by the artists who painted great masterpieces hundred of years ago and are still full of color today.

This paper will show how to relate reported lightfastness data to various display conditions. You will be able to project image life under the customer's expected display conditions. It will also examine some market perceptions about pigmented inks and high quality images. Finally, you will see tips and tricks for printing top quality, color saturated images with today's pigmented inks.

2. Introduction

Printers need to make images that look good when customers receive them. But those images also need to maintain that high quality for the duration of time that the customer will display them. How can a printer or a print buyer know whether their images will last? How can the printer generate longer lasting images? What can customers do to extend the life of these images?

There are many ways that images degrade. This paper will limit its discussions to fading from exposure to light.

Many printed images are only displayed for a short time, with no extreme lighting. But a substantial percentage will be displayed outdoors, or indoors for long times. Outdoor images see very bright light. Indoor images are exposed to a wide range of lighting from dim to very bright (Table I). Wilhelm and Brower reported measurements of real display conditions in a variety of situations.[1]

Table 1

Light Intensity at Various Display Conditions	
Display Condition	Exposure (Lux)
Outdoor Direct Sunlight	75,000-100,000
Indoor Glass Filtered Sunlight	40,000-60,000
Indoor Glass Filtered Indirect Sunlight	4000-9000
Indoor Spotlight (75 watt @ 3 feet)	5000-7000
Indoor Museum Lighting	55-1,000
Indoor Evening Room Lighting	75-450

When a print shop produces images for both indoor and outdoor display, it must use pigmented inks to produce the outdoor images. Dye inks simply will not last very long in outdoor lighting. When the next print job is for indoor display, dye based inks could be used to produce excellent images. But a percentage of the customers for those images will want to display them for long times, or will display them in a location where they are exposed to very bright light. Dye inks are not likely to meet their needs.

Dye images don't withstand bright light very well. Today's homes include extensive use of skylights, large glass windows, and sliding doors. Commercial buildings often use full glass walls in entry reception areas. Images displayed on these walls are exposed to more bright light than ever before. If these images are made with dye-based inks, what percentage of customers will be disappointed in the performance? What percentage of customers can a printer disappoint, before losing significant business?

If pigment inks could be used for those indoor images, no customers would be disappointed with early fading. In addition, printers would not need to change inks. But, can you get the image quality you need from pigmented inks? If you can, will the pigmented inks be robust enough in the printing process to perform reliably? Even if all of that is acceptable, the printer OEMs do not offer the printing substrates that customers require. Are these materials available? Where can a printer get them? We will deal with these questions one at a time.

3. Fading of Dyes and Pigments

Color in images is generated by color forming chromophores on either dye or pigment molecules. Dyes are soluble chemicals that exist in an ink as individual colorant molecules. Pigments are insoluble chemicals that exist in groups of thousands of colorant molecules.

Fading of color is from chemical reactions that cause the chromophore element to break down. Dyes fade faster than pigments under the same conditions. If you consider a light photon hitting a single dye molecule or a collection of pigment molecules, you can understand why this happens.
When a photon hits a molecule, its energy is distributed across the molecule. If the chromophore element receives enough energy, it will break down. Photon energy hitting a pigment particle is distributed over many molecules. Less energy reaches any particular chromophore element. Reactions occur a lower percentage of the time.

This difference can also be explained using the concept of activation energy. Distributing the energy so that less gets to the reaction sites is equivalent to increasing the activation energy barrier. More energy must hit the particle to get the same amount of reaction at the chromophore. For a given amount of incident radiant energy, you get less reaction. [2]

In recent years techniques have been developed to decrease the rate of dye ink color fade. This just means that images made with these inks can now withstand low lighting display for a reasonably long time. Unfortunately, under bright light, they still fade relatively quickly.

3a. Accelerated Testing

The best data on lightfastness would be from exposing samples in real display conditions and monitoring the fade. Unfortunately, the data is needed now and real-time tests would take years to get any results. Accelerated tests have been developed to simulate the effects at 7-10x the rate of change [3,4,5]

In accelerated testing the data is extrapolated from test condition to projected real-time condition. In a young technology like ink jet there is no data to define the acceleration rate. The starting approximation is usually that the change is directly proportional to exposure energy multiplied by exposure time, independent of exposure level (e.g., 1 year at 10,000 Lux would be considered equivalent to 20 years at 500 Lux).

History indicates that real-time light induced fading is more severe than projections from accelerated testing – often one and a half to two times the fade rate.[6] Preliminary data indicates this may also be the case for ink jet images. However, for the moment, the best first order approximation is that fading is proportional to the total energy multiplied by the exposure time.

3b. Outdoor Fading

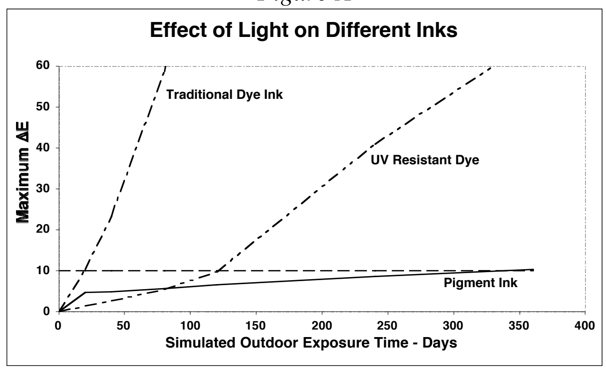
Outdoor lightfastness testing is often done in real time in South Florida or Arizona, but accelerated testing is usually done to get results faster. Figure A is an example of the rate of color change of various images under accelerated, simulated outdoor conditions, assuming that fading is proportional to cumulative energy-time.

The data was collected in La*b* color space and color change calculated as:

$$\Delta E = SQRT\ [(L_2-L_1)^2 + (a^*_2-a^*_1)^2 + (b^*_2-b^*_1)^2].$$

ΔE=10 is a change that can be easily observed. This is considered by many to be the failure criteria in La*b* space.

Figure A



Traditional dyes fade quickly and pass the failure criteria in a few days. Recent lightfast dyes last much longer – approximately 3 months. As you can see in Figure A, pigment inks are much more stable. They don't reach the failure criteria for a year.

In 1998, a test was run by Hewlett-Packard, 3M, and Amiable (now Scanvec). They covered a working trailer called the Trade Show Express with an advertising graphic that included vector and bit-mapped art printed with HP-UV pigment inks on 3M adhesive backed vinyl and the MCS laminate process. After one full year on the road in normal service, there was no noticeable fade. Test strips taken into the lab showed slight changes. Magenta was the worst primary color with ΔE = 5. Blue and Red had the largest changes with ΔE = 8 and 6, respectively. [7]

In summary, recent dyes have gotten much more fade resistant, but they still fade relatively quickly in bright light. Pigment inks are much more stable than the best dye inks.

3c. Indoor Fading

Wilhelm Imaging Research, Inc is the primary site for indoor image lightfastness. Wilhelm tests and publishes a wide range of data on dye and pigment inks tested as shown in Table 2.[8] He has established fading criteria for pure colors as well as for the difference in fading between pure colors to approximate changes in color intensity or hue that would become objectionable. A sampling of his data is in the Appendix. Note that lifetimes are projected using the assumption that fading is proportional to total Lux-hours.

It is important to note the reference condition of 450 Lux exposure for 12 hours/day that is used for projecting lifetimes. Using a reference condition allows you to compare different ink/media sets at the same condition. However, the lifetime reported at the reference is only valid for samples displayed at that condition. If exposure level is

Table 2

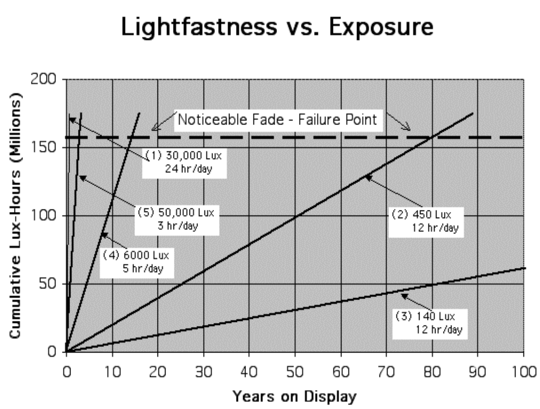
Test Conditions at Wilhelm Imaging Research, Inc. for Indoor Lightfastness	
Light Intensity	Approximately 30,000 Lux
Exposure Duration	24 hours/day
Sample Initial Optical Densities	Approximately 0.6
Temperature	75°F
Humidity	60% RH
Failure Criteria	See Reference [9]
Acceleration Assumption	Fading proportional to total Lux-Hours, independent of exposure light intensity.
Reference Condition for Projected Lifetime	450 Lux Exposure for 12 hrs/day

lower, the image will last longer. If exposure is higher, the image will fade faster.

The data in the Appendix show that Encad GA and GS, early large format inks, will only last 1-2 years. More recent dye inks will last up to 80 years at the reference conditions. Pigment inks are much more stable. One set being tested is projected to fail at 120-130 years. None of the other pigmented inks on test have faded past any of the failure criteria. Some have already been on test long enough to simulate 200 years of exposure at 450 Lux for 12 hours/day – and they are still going strong.

If your choice is between material that will last 80 years or 200 years, either choice will meet most needs. Only images with intrinsic emotional value, like wedding pictures or family portraits, need the extra lifetime. However, reported lifetimes are only valid if you control the display conditions to the reference conditions used for the projection. What happens to images displayed under a spotlight or exposed to sunlight filtered through glass? Figure B shows the effect of light intensity on lifetime.

Figure B



This chart starts with line (1) that shows the increasing Lux-hours of exposure during a test with lighting at 30,000 Lux-24hr/day. On some regular basis the samples are tested. At a certain point, one of the established fading criteria is passed. In this Figure the failure criteria was reached after 157×10^6 Lux-hours. This defines the "Noticeable Fade – Failure Point" line.

Now we can calculate how long it will take to reach this Failure Point if exposed at various lighting intensities. Line (2) shows what happens at 450 Lux-12hrs/day. This simulates 12 hours of indoor museum lighting. Under these conditions, failure is reached in 79 years.

$$(157 \times 10^6 \text{ Lux-Hours})/450 \text{ Lux}/(12\text{hrs/day})/365\text{days/yr} = 79 \text{ yrs}$$

This is the basis of Wilhelm Imaging Research, Inc. results.

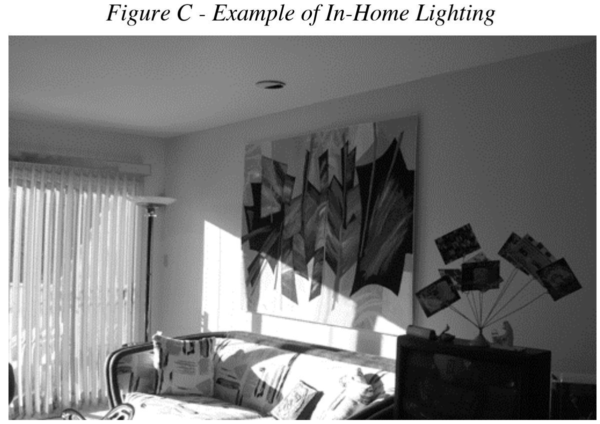
Some people believe that since many images are displayed under lower light conditions the standard display condition should be 140 Lux for 12 hr/day. Curve (3) shows what happens at that condition. If this curve is extended to the Failure Point, it will reach it in 288 years (off the chart).

But what happens if the customer puts a spotlight on the image to highlight the colors? If the display condition were 6000 Lux for 5 hours a day (Line 4), the 80-year ink would fail in 14 years. Much shorter, but still not too bad.

Finally, what if sunlight streams across the image for a few hours a day with exposures of 50,000 Lux. Now line (5) applies and the image fades to failure in less than 3 years.

Some people call these latter situations "inappropriate display conditions." However inappropriate they may be, it is real world. One piece of art in my living room is lighted with a recessed 75-watt spotlight. The light hotspot is 6000 Lux. Figure D shows a different wall in the same room when the rising sun beams through the glass doors and vertical blinds. The light intensity here has been measured at 50,000 Lux. I guess I'm just an inappropriate customer!

Figure C - Example of In-Home Lighting



Drop on demand ink jet has now improved to the point that high quality art and photographic images can be produced. Customer expectation is that these will last and can be enjoyed by children and grandchildren. That won't happen with dye-based inks unless care is taken to avoid high intensity light exposure.

The pigment inks on test right now have already been on test 2-1/2 times longer than it took the most stable dye ink to fail. Their fading is still well under the limit. Given the high intensity display conditions that often occur in the real world, the pigmented inks will last much longer than the dye inks and are much more likely to meet customer's needs.

4. Pigment Inks & Quality Images

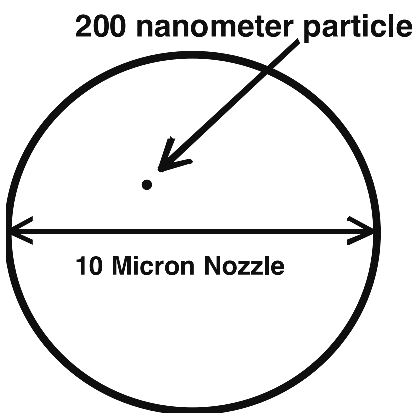
Quality of an image forming ink must meet three major criteria. First, the ink must perform reliably in the process. In a production environment, the printer can't afford to have nozzles clog and leave streaks in the image. Next, the inks must have the ability to make bright colors to match the pallet of an artist or the colors in a photograph. Lastly, the ink must be able to make high resolution, pleasing images.

4a. Pigment Ink and Printer Reliability

There is a perception in the market that pigmented inks contain chunks of colorant that plug nozzles. This may happen with some inks; but not in quality pigmented inks. In order for any CMYK process ink set to give decent color, the ink must be transparent and must not scatter visible light. To do that, particles must be less than half the shortest wavelength of light, 400 nanometers. That means the pigment particles must be less than 200 nanometers. Figure D shows a 200 nanometer particle in a 10 micron nozzle. There is no way that this particle will plug that nozzle.

There is no question that if either dye or pigment inks are allowed to dry in the nozzle they will plug it. But pigment particles in properly made ink won't plug nozzles.

Figure D – Pigment Size vs. Nozzle Diameter



4b. Pigment Ink Color Gamut

There is also a perception that pigmented inks don't have much color gamut. You have probably seen outdoor signs made with pigmented inks that had a dull, and lifeless image. What you probably didn't know was not the ink that caused the but rather the mismatch of ink and media. Matched ink and media are critical to bringing out the color.

Color space is three-dimensional. Figure E shows the representation of this three dimensional space and how we project the shadow of this space in the Brightness (L) axis to give a two dimensional representation. If we look only at the primary and secondary colors in the projection, we can generate charts like Figure F.

Figure E – 2D Projection of 3D Color Space

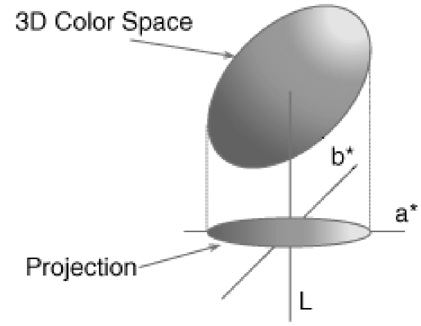
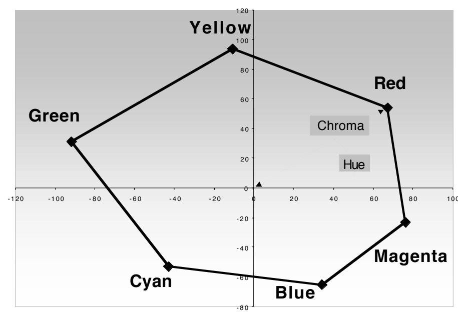


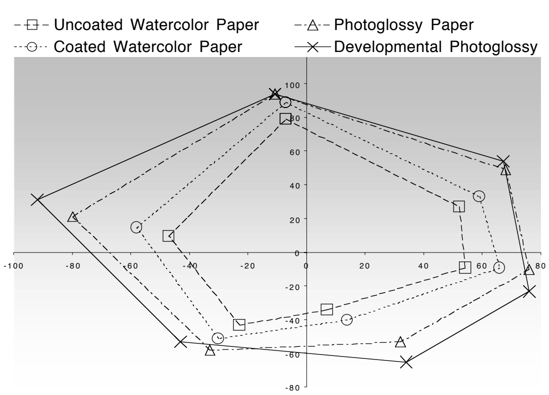
Figure F – 2D Projection of 3D Color Space



The (0,0) point is the Lightness axis, which is perpendicular to the paper. The angle relative to the positive x-axis is the Hue, which defines the color. The distance from (0,0) is the chroma and measures saturation.

The significance of media is shown in G. Here you see a particular ink on a range of media: Uncoated Watercolor Paper, Coated Watercolor Paper, a Photoglossy Paper with well matched coating, and a Developmental Photoglossy with an exceptionally well matched coating.

Figure G – Media Effect on Color Space Projection

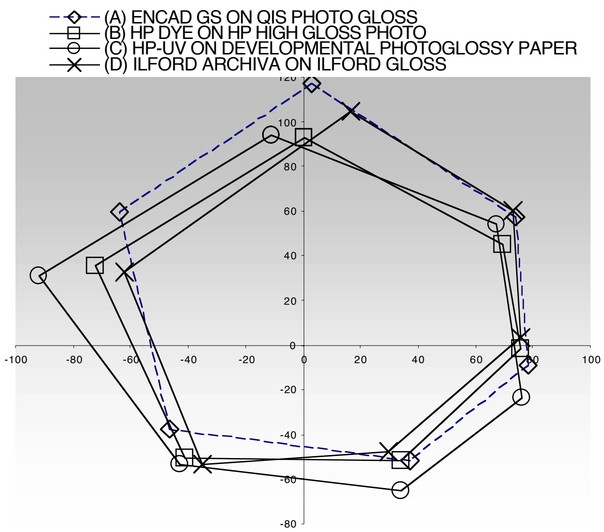


The color gamut, which can be looked at as the volume in La*b* space, varies by a factor of 4. Well matched media are obviously important for getting bright colors.

Now we can compare some dye inks printed on recommended media with a pigment ink set on a matched media. (See Figure H.) What is important to recognize from Figure H is that the color gamuts available with dye inks or pigment inks, when printed on matched media, are similar. There are differences, but they are subtle.

Comparing the inks in Figure H you find that the pigment inks have a yellow shifted toward green. This generates a green more saturated than the dye inks, but it does limit red saturation. However, the differences are minor and are only noticeable in side-by-side comparison

Figure H – Dye vs. Pigment Color Space



4c. Image Quality with Pigmented Inks

The final perception is that pigmented inks cannot make high quality images. Unfortunately images can't be shown in this paper. But the perception is false. There are water-based pigment ink printers by Hewlett-Packard, Encad, Epson, Roland, Colorspan, and Mimaki that make bright colored high qualtiy images. Artists can't believe how good the reproductions are. The watercolors look like originals. Museum curators have sometimes shown concern that these images could pass as originals. They are that good.

I recommend that you visit a digital printing trade show and pick the printer that meets your needs for image quality, purchase price, materials costs, productivity, and environmental friendliness. Then print with pigment inks designed for that printer. Start with the media recommended by the vendor, but try the third party media described in Table 3. I'm sure that you will be amazed with the results.

5. Tips for Printing Pigmented Inks.

To get the best images from your printer take control of your printing. OEMs establish default settings to work reasonably well for any image. That often means a compromised condition to assure that the most difficult images still look reasonable. Learning the machine at the default conditions is fine. But you should also work to identify optimized conditions for your specific images.

5a. Color Management

Default printing conditions are usually set to simulate SWOP or Eurostandard inks, or to print with greatly reduced ink loading. Ink Jet Inks have brighter color capability than SWOP and Eurostandard inks. You should turn off the Color Management that tries to match those inks and allow the printer to use the full range of the inks that you are printing.

Finally to determine whether or not you are taking full advantage of your ink's color capability, try to print blocks of pure Yellow, Cyan, and Magenta. If you send a pure color to the printer and you get a block contaminated with dots of other colors, you are not achieving the highest gamut that your inks could produce. When you print images using the same workflow, their color saturation will be artificially restricted. Find a way to turn that type of Color Management off. The Technical Service people at your printer vendor can help you determine how to do that.

5b. Media Optimized for Pigment Performance

Once your printer is able to print its ink at maximum saturation, you must consider the media onto which you are printing. You should start with the vendor's recommended media. However, you will often find that 3rd party media are better optimized for your particular ink set. Table 3 shows several media companies with materials that perform well with pigmented inks. The specific materials noted in Table 3 are just examples. Contact each of these vendors and ask them which media they have that can produce top quality images with pigmented inks on the kinds of substrates that your customers need.

Table 3 – Media Matched to Pigmented Inks

Vendor	Media Types
Hewlett-Packard	Colorluscent Backlit Film, Studio Canvas, Colorfast Vinyl
Encad	QIS Canvas, QIS PSA Vinyl
Mitsubishi Digital Imaging	Photoglossy and Photo Matte Paper Photoglossy Film, Backlit Film
Sihl	PhotoSatin Paper
AGFA	Photoglossy and Photomatte Paper
Hahnemühle	Watercolor paper
3M	Vinyl (PSA)
Accuplot	Photoglossy White Film
Asahi Pictorico	Photoglossy White Film
Rexam	Photoglossy Paper, Vinyl Synthetic Paper
Arkwright	Artist Canvas

5c. Multi-Color Black vs. pure Black

To make a good black with dye-based inks, most suppliers print 3 color (CMY) or 4 color (CMYK) black. They don't have a dark black ink, but they can get a good black with multi-color black. If you print this way with pigmented inks, you will not produce what you want.

Pigment inks have a black made from carbon black. They can make deep, dark blacks. However, CMY mixtures of pigmented inks often gives muddy looking dark gray.

If your pigmented images have low contrast and have muddy looking blacks, you need to modify your files to replace equal amounts of C, M, and Y with some amount of K – particularly in shadow areas. If your printing workflow sends RGB files to a RIP that uses ICC profiles, you can accomplish this with Gray Color Replacement (GCR) in your ICC profile. If you can't do it within your profile, you should consider converting your file from RGB-to-CMYK in Photoshop using GCR. Of course, if you normally send CMYK files to your printer, make sure that your RGB-to-CMYK conversion uses GCR to limit use of 3-color black in the high ink loading regions.

6. Summary

In summary, dye images will last a long under the very controlled "standard" conditions reported in the literature. However, if those images are exposed to outdoor light or bright indoor light, the best of the dye inks will fail much earlier than the reported lifetimes.

Pigment inks last years outdoors and generations indoors. If printed on matched media using proper color management, they can produce fine art images that nearly duplicate the original, and signs and banners with all the bright colors needed for eye-catching advertisements.

Appendix

Ink Jet Inks and Media.
Years of Print Display Before Noticeable Fading Occurs – Updated June 14, 2000

Ink	Media	Lifetime (yrs at 450 Lux-12 hrs/day)
Dye Inks		
Encad GA and GS Dye Inks	Encad QIS PhotoGlossy Paper and QIS Canvas	1-2 years
American Ink Jet UV Gold Inks	AIJ UV Gold Glossy Paper	30-35 years
AIJ Pinnacle Gold for Iris	Various Watercolor Papers	22-75 years
	Iris Canvas	24-28 years
Iris Equipoise Dye Ink	Various Watercolor and Canvas Media	7-36 years
Lysonic WH-2 Hybrid Ink Set	Various Watercolor Papers	20-36 years
	Iris Canvas	10-12 years
Lysonic WH-3 Ink Set	Somerset Velvet Paper	65-75 years
Ilford Archiva Dye Inks	Ilfojet Photo Glossy Paper(Much less stable with other media.)	70-80 years
Pigment Inks		
Roland Pigmented Inks	Legion Concord Rag Watercolor Paper	120-130 years
Encad GO Pigmented Inks	Encad QIS PhotoGlossy Paper and QIS Canvas	>100 years
HP CP Pigmented UV Inks	HP Studio Canvas,Hahnemühle Albrecht Durer Watercolor Paper	>140 years (tests ongoing)
	Arches Hot Press Paper, Legion Waterford DI Paper	>200 years (tests ongoing)

Data extracted from www.Wilhelm-Research.com

References

[1] H. Wilhelm and C. Brower, **The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures**, Preservation Publishing Company, Grinnell, Iowa, 1993, pp. 620-624.

[2] David J. Matz, **"Pigmented Inks: Opportunities in Digital Printmaking**," Digital Printing & Imaging Assoc., 8th Annual Conference, Published in the DPI 2000 Virtual Conference at www.dpia.org/dpipriv/vconf.html.

[3] American Society for Testing and Materials, Test G26-93, **Standard Practice for Operating Light-Exposure Apparatus (Xenon-Arc type) With and Without Water for Exposure of Nonmetallic Materials**, September 1993.

[4] Society for Automotive Engineers, Test SAE J1960, **Accelerated Exposure of Automotive Exterior Materials Using Controlled Irradiance Water Cooled Xenon Arc Apparatus**, June 1989.

[5] American National Standards Institute, Inc., Reference Document Number ISO/WD#2 18909, Proposed by IT9.3 Committee**, "Photography — Processed photographic colour films and paper prints — Methods for measuring image stability,"** New York, New York, March 7, 2000.

[6] H. Wilhelm and C. Brower, **The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures**, Preservation Publishing Company, Grinnell, Iowa, 1993, pp. 67-75

[7] Reported by Marsi Bennett, HP Marketing Manager at DPI 2000, March 10, 1999.

[8] Wilhelm Imaging Research, Inc., Grinnell, Iowa. Detailed results available at www.Wilhelm-Research.com.

[9] H. Wilhelm and C. Brower, **The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures**, Preservation Publishing Company, Grinnell, Iowa, 1993, pp. 90-93.

Biography

Dr. Matz received his B.S. in ChE from the University of Pennsylvania and his M.S. and Ph.D. in ChE from the University of Wisconsin, specializing in mechanical properties of polymers. His professional career has spanned Research and Development, Manufacturing, and Marketing, mostly aimed at electronic materials development. Ten years ago his efforts shifted to ink jet printing. In recent years his focus has been to stimulate the market to develop materials and processes to optimize archival pigment ink images.