Accelerated Laboratory Testing: Developing Meaningful Test Methods for Evaluating Light Stability of Ink Jet Images

Eric T. Everett
Q-Panel Lab Products,
Cleveland, Ohio, USA

Abstract

As reproduction of digital images with ink jet printers becomes increasingly popular, so too does the demand for images which are lightfast and meet customer expectations. Manufacturers of ink jet inks and media need light stability test methods using accelerated laboratory test apparatus that can better help them predict the durability of their product. Accelerated laboratory testing provides reproducible results for materials exposed to specific sets of conditions. It is intended to determine material durability and improve material formulation.

The first part of the paper provides a history of accelerated laboratory testers, including carbon arc, fluorescent UV, and xenon arc. The inherent strengths and weaknesses of each type of tester will be reviewed. Background is also provided on sunlight and spectral power distributions.

The second part of the paper reports on (1) publication of new ASTM performance-based specifications for laboratory weathering test apparatus; (2) recent standards activities for lightfastness testing of printing inks and artists' materials; and (3) development of appropriate test methods suited to products and their end-use environments.

Introduction

Sunlight is an important cause of damage to printing inks, paints, sealants and other organic materials. Short wavelength ultraviolet and visible UV light is recognized as being responsible for most of this damage. Accelerated weathering testers employ a variety of light sources to simulate sunlight and the damage caused by sunlight. The various types of accelerated testers produce a variety of UV spectra based upon the type of light source being used.

The simulation of sunlight can be produced by a variety of accelerated light sources, such as a Carbon Arc or Xenon Arc, for example. Such light sources will be compared with sunlight relative to performance of reproducing the UV portion of the light spectrum.

Sunlight

The electromagnetic energy from sunlight is normally divided into ultraviolet light, visible light, and infrared energy. Figure 1 shows the spectral power distribution (SPD) of noon mid summer sunlight. Infrared energy (not shown) consists of wavelengths longer than the visible red wavelengths and starts above about 760 nanometers (nm). Visible light is defined as radiation between 400 and 760 nm. Ultraviolet light consists of radiation below 400 nm.

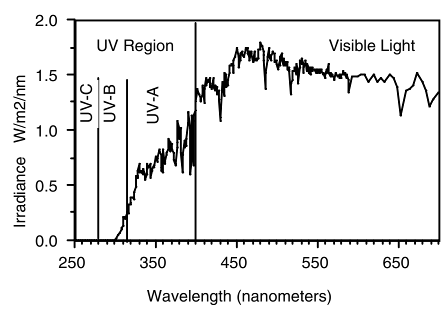

Figure 1.The Sunlight Spectrum

Accelerated Light Sources Compared to Sunlight

For simulations of direct sunlight, artificial light sources should always be compared to what we call the Solar Maximum condition: global, noon sun light, on the summer solstice, at normal incidence. This is the most severe condition met in outdoor service, and as such it controls which materials will fail. Graphs labeled "sunlight" in this paper refer to Solar Maximum.

Importance of Short Wavelength Cut-off

Photochemical degradation is caused by photons of light breaking chemical bonds. For each type of chemical bond there is a critical threshold wave length of light with enough energy to cause a reaction. Light of any wavelength shorter than the threshold can break the bond, but longer wavelengths of light cannot break it - regardless of their intensity (bright ness). Therefore, the short wavelength cut-off of a light source is of critical importance.

For example, if a particular polymer is only sensitive to UV light below 295 nm (the solar cut-off), it will never experience photochemical deterioration outdoors. If the same polymer is exposed to a laboratory light source that has a spectral cut-off of 280 nm, it will deteriorate. Although sources that produce shorter wave lengths produce faster tests, there's a possibility of anomalous results if a tester emits these unrealistic wavelengths.

Carbon Arc

Enclosed Carbon Arc. The enclosed carbon arc has been used as a solar simulator in accelerated weathering and lightfastness testers since 1918. It is usually considered obsolete because of its poor match with sunlight and its lack of short wavelength UV.

Sunshine Carbon Arc. The introduction of the sunshine carbon arc in 1933 was an advance over the enclosed carbon arc. Figure 2 shows the UV SPD of summer sunlight compared to the SPD of a sunshine carbon arc (with Corex D filters). While the match with sunlight is superior to the enclosed carbon arc, there is still a very large spike of energy, much greater than sunlight, at about 390 nm (Figure 2).

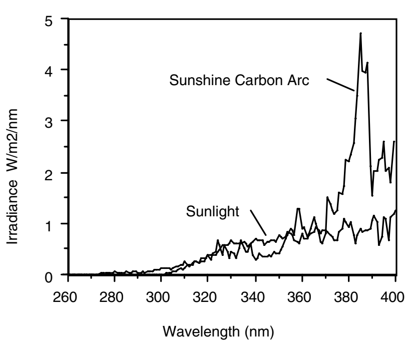

Figure 2. Sunshine Carbon Arc and Sunlight

A more serious problem with the spectrum of the sunshine carbon arc is found in the short wave lengths. Figure 3 shows Solar Maximum compared to sunshine carbon arc between 260 nm and 320 nm. The carbon arc emits a great deal of energy in the UV-C portion of the spectrum, well below the normal solar cut-off point of 295 nm. Radiation of this type is never found at the earth's surface. These short wavelengths can cause unrealistic degradation when compared to natural exposures.

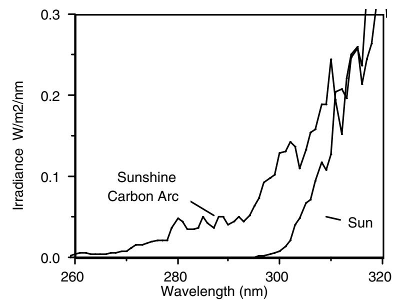

Figure 3. Sunshine Carbon Arc and Sunlight

Xenon Arc

The xenon arc was adapted for accelerated weathering in Germany in 1954. Xenon arc testers, such as the Q-Sun Xenon Test Chamber, are appropriate for photostability of materials because they provide the best available simulation of full spectrum sunlight:UV, visible & IR light. Xenon arcs use filters to achieve the appropriate spectrum (e.g., outdoor sunlight or sunlight filtered through window glass).

Effect of Xenon Filters. Xenon arcs require a combination of filters to reduce unwanted radiation. The most common filter combination is the “Daylight” Filter. Figure 4 shows the SPD of noon summer sunlight compared to a xenon arc with a Daylight Filter.

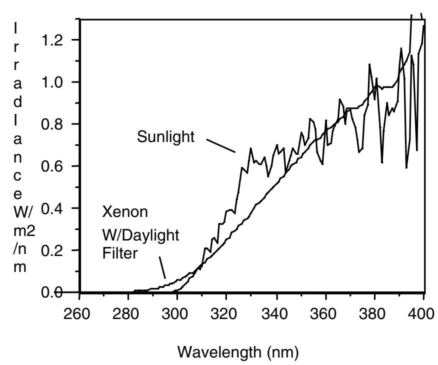

Figure 4. Xenon with Daylight Filter

Another type of xenon arc filter that is intended to simulate sunlight through window glass is the “Window Glass” Filter. It is typically used to test products whose primary service life will be indoors. Figure 5 shows the SPD of noon summer sunlight behind glass compared to a xenon arc with a Window Glass Filter.

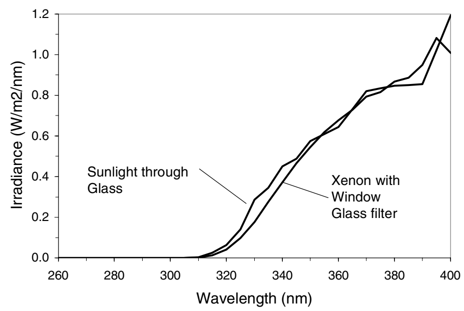

Figure 5. Xenon with Window Glass Filter

Xenon Arc Moisture. The xenon arc uses a system of intermittent water spray to simulate the effects of rain and dew. The water spray cycle is especially useful for introducing thermal shock and mechanical erosion.

Effect of Irradiance Setting. Modern xenon arc models, including the Q-Sun, have a light monitoring system to compensate for the inevitable light output decay due to lamp aging. The operator presets a desired level of irradiance or brightness. As the light output drops off, the system compensates by increasing the wattage to the xenon burner. The most common irradiance settings are 0.35 or 0.55 $W/m^2/nm$ at 340 nm. Figure 6 shows how these two irradiance settings compare to noon summer sunlight.

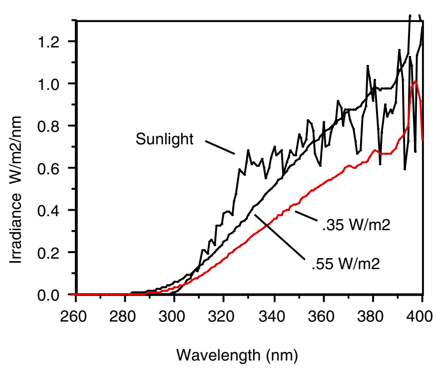

Figure 6. Effect of Irradiance Setting

Several different sensors to measure and control irradiance are available (depending on the manufacturer): 340 nm, 420 nm, TUV, or total irradiance. The difference between these sensors is the wavelength or wavelength band at which they control the irradiance, and the wavelength or wavelength band to which they are calibrated (through a NIST-traceable calibration radiometer).

The 340 nm sensor measures a narrow band of wavelengths centered on 340 nm, with a half-bandwidth of 10 nm, and should be used when testing materials that are primarily damaged by short-wavelength UV. This is because even as lamps age and the spectrum shifts, the 340 nm setting will still be maintained. Generally, this is a good control point for paints, plastics, roofing, and other typically durable products.

The 420 nm measures a narrow band of wavelengths centered on 420 nm, with a half-bandwidth of 10 nm, and should be used when testing materials that are primarily damaged by visible light, such as dyes and pigments in textiles, papers, and inks. In general, the broader-band TUV and total irradiance sensors are not recommended.

Several factors complicate controlling the irradiance from a xenon burner: solarization of the filters and aging of the burner. Either of these factors may cause the xenon SPD to change non-uniformly – the short wavelength output drops off more rapidly than the longer wavelength output.

Figure 7 shows the SPD of one burner measured at four different times in its life. Irradiance is monitored and controlled only at 340 nm. A wattage increase that is sufficient to maintain irradiance at 340 nm is not enough to compensate for the fall off below 340 nm. At the same time, the higher wattage causes an increase in the visible light output from the burner. This changes the spectral power distribution of the lamp. The figure shows that, while the irradiance controller does a good job at 340 nm, there is a drop in irradiance in the short wavelength UV portion of the spectrum.

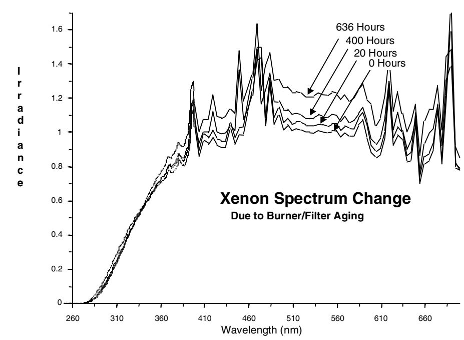

Figure 7. Xenon Spectrum Change Due to Aging

This change in spectrum due to aging is an inherent feature of xenon arc lamps. However, this can be compensated for by regular replacement of lamps.

QUV Accelerated Weathering Tester

World wide, QUV testers are the most widely used type of weathering tester. These fluorescent UV testers use a different approach than the arc testers. They do not attempt to reproduce the entire solar spectrum, just the damaging effects of sunlight. This approach is effective because short wavelength UV causes almost all of the damage to durable materials exposed outdoors. Consequently, fluorescent UV testers confine their primary emission to the UV portion of the spectrum. Different types of fluorescent lamps, with different spectrums, are used for different exposure applications.

UVB Lamps. There are two types of UVB lamps, the FS-40 and the UVB-313. The FS-40 lamp is used primarily by the automotive industry. The UVB-313 is essentially a second generation FS-40. It has the same SPD as the FS-40, but with a higher, more stable output. Figure 8 shows the SPD of noon, summer sunlight compared to the UVB-313 and the FS-40 lamps.

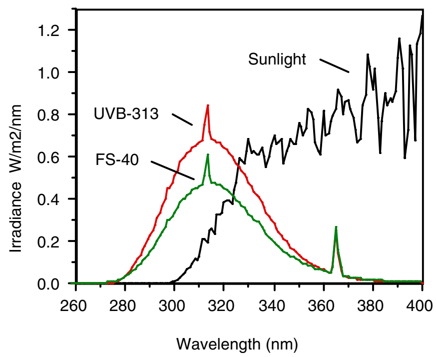

Figure 8. UVB-313 and FS-40

UVA-340 Lamp. The UVA-340 was introduced in 1987 to allow enhanced correlation. The UVA-340 has been tested on various polymers and greatly improves the correlation that is possible with the QUV. Figure 9 shows the UVA-340 compared to the Solar Maximum. This lamp is an excellent simulation of sunlight from about 365 nm, down to the solar cut-off of 295 nm. It is the best simulation of sunlight below 365 nm. The UVA-340 lamp gives excellent, relative predictions of how materials will fare when exposed outdoors.

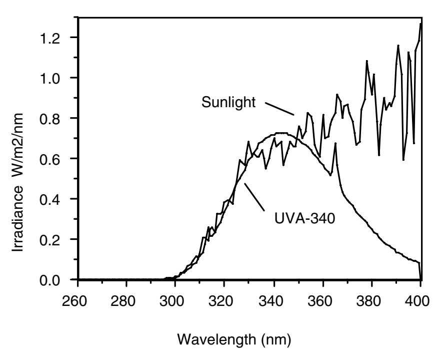

Figure 9. UVA-340 and Sunlight

Cool White Fluorescent Lamps. In the field of color photography, Cool White lamps have been used to simulate indoor home or office environments. *ANSI/NAPM IT9.9 Methods for Measuring - Color Photographic Images* specifies a glass-filtered Cool White Fluorescent test at 6.0 klux. The QUV tester can be used for this type of indoor light stability testing. The Cool White lamp spectrum has energy spikes at approximately 436 nm and 546 nm. However, the spectrum does not address sunlight that may enter an indoor environment through a window or glass door. For indirect daylight simulation and outdoor daylight simulation, xenon arc testers are specified in IT9.9.

Irradiance Control in the QUV. Another advantage for the reproducibility of test results in the QUV is the irradiance control system. Newer models of the QUV are equipped with a system called the Solar Eye, which consists of a programmable controller that continuously monitors the UV intensity via four sensors mounted in the test sample plane.

A four-channel feedback loop system maintains the programmed irradiance level by adjusting power to UV lamps. Figure 10 shows a simplified schematic of how the irradiance control system works. The user sets the level of desired irradiance and the Solar Eye maintains it automatically.

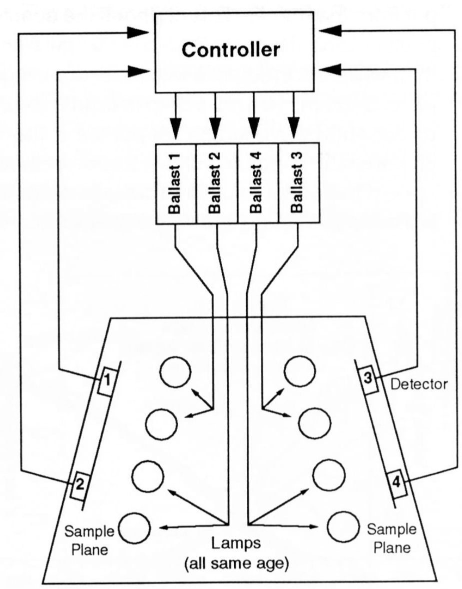

Figure 10. Solar Eye Irradiance Control

QUV Moisture. Outdoors, materials are frequently wet up to 12 hours each day. Research indicates that the main cause of this outdoor wetness is not rain, but dew. The QUV simulates this by means of a unique condensation mechanism. During the QUV condensation cycle, a water reservoir in the bottom of the test chamber is heated to produce vapor. The hot vapor maintains the chamber at 100% relative humidity and at an elevated temperature. The QUV is designed so that the test specimens actually form the sidewall of the chamber. Thus, the reverse side of the specimens is exposed to ambient room air. Room air-cooling causes the test surface to drop a few degrees below the vapor temperature. The temperature difference causes liquid water to continually condense on the test surface throughout the condensation cycle. The resulting condensate is very stable, pure distilled water. This pure water increases the reproducibility of test results and precludes water-spotting problems.

Because outdoor exposure may produce wetness up to 12 hours a day, QUV wet periods also usually last for several hours. We recommend programming each condensation period to at least four hours. Note that the UV exposure and condensation exposure occur separately in the QUV, just as they do in natural weathering.

Conclusions About Accelerated Laboratory Testers

1. The Carbon arc tester exhibits variability in output due to the aging of its filters. In addition, this type of tester is increasingly becoming obsolete.
2. The QUV tester provides the best available simulation of short wavelength sunlight with UVA-340 lamps. It provides a very stable light spectrum in the UV region. It can also be equipped with Cool White fluorescent lamps to perform indoor light stability testing measured in lux. The QUV's condensation cycle provides the most realistic and severe moisture attack. It is appropriate for physical properties testing, as well as indoor light stability testing.
3. The Xenon arc tester (e.g., Q-Sun) provides the best avaible simulation of full spectrum sunlight (UV, Visible, IR). It can simulate outdoor sunlight with a Daylight Filter. It can simulate indoor daylight with a Window Glass Filter. It is appropriate for fading, color change & yellowing test applications. The Xenon arc is especially useful for testing of printing inks, which are sensitive to long-wave and visible light

With any accelerated laboratory tester, there are a number of parameters that must be programmed: UV spectrum, moisture, humidity, temperature and test cycle. Because no one test cycle or device can reproduce all the variables found outdoors in different climates, altitudes and latitudes, the accelerated conditions that one chooses are, to a certain extent, arbitrary. In order to achieve rapid test results, an accelerated tester must often exaggerate the naturally occurring degrading forces found in nature. Material formulations that differ significantly may react in various ways to these artificially severe stresses. Consequently, generically different material types may exhibit different acceleration factors. In fact, even within one individual textile material, there may be different acceleration rates for different properties examined.

The spectrum of a test device is only one part of the picture. The real usefulness of accelerated testers is that they can give reliable, relative indications of which material performs best under a specific set of conditions.

Correlation between laboratory and natural exposure test results will probably always be controversial. Test speed and accuracy tend toward opposition. Accelerated light sources with short wavelength UV give fast tests, but may not always be accurate. That is, they may be too severe and cause unrealistic photodegradation. Light sources that eliminate wavelengths below the solar cut-off of 295 nm will give better, more accurate results, but the price for increased correlation is reduced acceleration. The user must educate himself to make this choice—Simulation vs. Acceleration.

New ASTM Performance-Based Specifications for Accelerated Laboratory Light Sources

Several years ago, ASTM Committee G03 on Weathering & Durability began the process of creating new, performance-based specifications that were intended to replace older, hardware-based G23 (carbon arc), G26 (xenon arc) & G53 (fluorescent UV) specifications. ASTM G151 provides general guidelines to users for operating the various test apparatus (1). ASTM G152 is the performance-based specification for open flame carbon arcs (2). ASTM G153 is the performance-based specification for enclosed carbon arcs (3). ASTM G154 is the performance-based specification for fluorescent UV light apparatus (4). ASTM G155 is the performance-based specification for xenon arcs (5). The G151-G155 test specifications were first published in 1997. Subsequent 1998 and 2000 editions of the documents were also published.

Developing Appropriate Test Standards for Light Stability Testing

The proliferation of digital imaging has resulted in mismatching of paper/ink/coating. Therefore, there is a need for a matched system of ink & paper. The problem is that with all the choices of printer papers & inksets available, manufacturers cannot predict all the possible combinations of their product and make meaningful service life predictions.

Consequently, there is an urgent need for a standardized light stability test procedure. The digital imaging industry has had to create their own de facto standard to keep up with consumer demand. Presently. there is no industry standard for measuring ink jet print life. Following are some current industry standards activities addressing light stability testing.

ANSI/ISO IT9.3 Stability of Color Pictorial Images Subcommittee is working towards defining a representative nominal indoor test condition for light stability testing of digital images produced from inkjet or laser printers. The new standard will be based on ANSI/NAPM IT9.9 (Methods for Measuring Color Photographic Images). IT9.9 is based on upon significant research conducted by Henry Wilhelm. IT9.9 defines the method for testing (xenon arc & fluorescent UV), but sets no endpoints for predicting print life.

In addition, the IT9.3 Subcommittee is working on development of standards to test outdoor durability of marking materials (e.g., banners, vinyl signs, buswraps, etc.).

ASTM D01.56 Lightfastness of Printing Inks Subcommittee has updated ASTM D3424, "Test Method for Evaluating Lightfastness & Weatherability of Printed

Matter" to reference the G155 performance-based xenon arc standard.

ASTM D20.50 Durability of Plastics Subcommittee is revising ASTM D4674, "Test Method for Accelerated Testing for Color Stability of Plastics Exposed to Indoor Fluorescent Lighting and Window-Filtered Daylight" from a Test Method to a Standard Practice. The performance-based revisions will allow three testing options (i.e. UVB lamps behind glass and cool whites, UVA-340 lamps behind glass and cool whites and cool whites only).

In 1999, the *ASTM D01.57 Artists' Materials Subcommittee* began a study to help artists better predict the longevity of their works after prolonged exposure to light. The correlation study compared natural outdoor and accelerated laboratory exposures for lightfastness testing of artists' pencils. The results of the study will be used to write a standard test method that distinguishes between various colored pencil quality levels.

The study compared Florida and Arizona natural exposures (under glass) with three models of xenon arc testers. Three colored pencil manufacturers supplied two replicates of 15 colored pencil types. The Society of Dyers and Colourists (SDC) supplied eight blue pigmented paper types. The Colored Pencil Society of America (CPSA) supplied four different blank paper substrates.

The results of the study indicated that absolute correlation between the natural and accelerated laboratory exposures was poor. However, rank order correlation of the same exposures was excellent. The Q-Sun 1000 table-top xenon arc tester gave the same results as the Florida Under Glass and Arizona Under Glass exposures, as well as with the larger Atlas Ci35 xenon-arc tester. In addition, relative humidity had very little effect on the test specimens. In the xenon exposures, there was no noticeable difference between specimens exposed in a humidity-controlled xenon-arc tester with similar specimens exposed in a xenon-arc tester without humidity control.

Future Work

More testing is needed to address the complex inter-relationship between coating/ink/substrate. Initial ruggedness tests of various paper substrates indicate a direct relationship between the effect of the paper substrate on an ink's durability to UV exposure. In conclusion, there are several accelerated light stability testing options available depending upon one's needs. For example, Fluorescent UV testing in a QUV using cool white lamps and/or UVA & UVB lamps is appropriate for simulating indoor lighting conditions. Xenon arc testing with a Window Glass Filter is appropriate for simulating sunlight through a window, while xenon arc testing with a Daylight Filter is appropriate for simulating outdoor exposure to sunlight. In addition to accelerated laboratory testing, natural outdoor exposure testing should always conducted (i.e. direct & behind glass exposures) to establish an appropriate benchmark for end use applications and service environments.

References

1. ASTM G151, Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources.
2. ASTM G152, Standard Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials.
3. ASTM G153, Standard Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials.
4. ASTM G154, Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials.
5. ASTM G155, Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Nonmetallic Materials.

Biography

Eric Everett received his B.A. from Baldwin-Wallace College and M.A. from Case Western Reserve University in 1987 and 1989, respectively. Eric is employed as a Technical Specialist for Q-Panel Lab Products Co. He has 10 years of experience in standards development. He is Secretary for ASTM G03 Committee on Weathering & Durability and ASTM D01.27 Subcommittee on Accelerated Tests for Protective Coatings. He is also a member of ANSI/ISO IT9.3 on Stability of Color Pictorial Images.