TECHNICAL BULLETIN LU-8004

The QUV Tester Compared to Sunshine Carbon Arc

Weathering is an important cause of damage to plastics, textiles, coatings, and other organic materials. Accelerated weathering testers are used to simulate this damage for research and development, quality control, and material certification. Two popular accelerated testers are the QUV® Accelerated Weathering Tester (ASTM G-53) and the Sunshine or "open flame" Carbon Arc (ASTM 6- 23). The testers differ in several important areas: light spectrum, method of moisture simulation, required maintenance, price and operating cost.

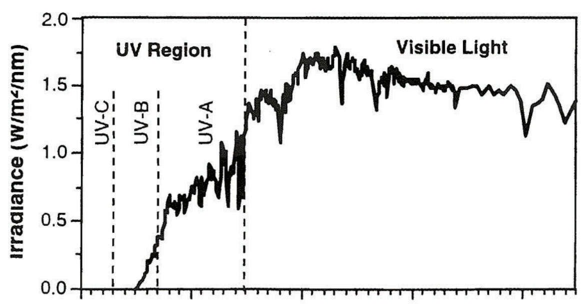

Figure 1 - The Sunlight Spectrum

Emission Spectra. The Sunshine Carbon Arc has been used since 1933 for accelerated weathering and lightfastness testing. Some Federal Test Methods still require its use. Carbon arcs were designed on the idea that, to simulate sunlight, it is necessary to reproduce the entire spectrum of sunlight. The QUV tester uses a different approach. QUV lamps do not attempt to reproduce sunlight itself, just the damaging effects of sunlight. This approach is effective because short wavelength UV causes most of the damage to durable materials exposed outdoors. Consequently, QUV lamps confine their primary emission to the UV portion of the spectrum. This results in different spectra from the carbon arc and, usually, different test results. To understand the difference between the carbon arc and the QUV tester, it's necessary to first look at the spectrum of sunlight.

The Sunlight Spectrum. 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. The International Commission on Illumination (CIE) further subdivides the UV portion of the spectrum into UV-A, UV-B and UV-C as shown below.

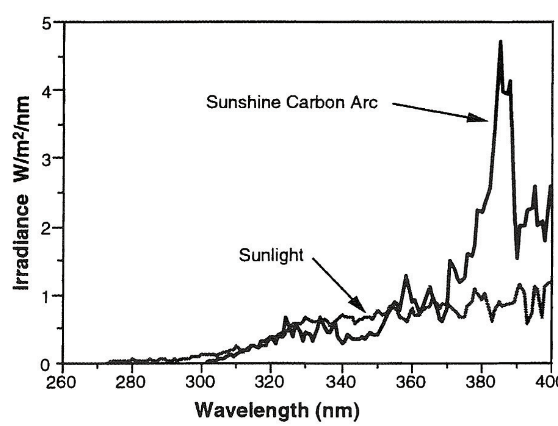

Figure 2 - Sunshine Carbon Arc and Sunlight

Importance of Short Wave Cut-Off. Photochemical degradation is caused by photons of light breaking chemical bonds. For each type of chemical bond there is a critical threshold wavelength 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 (brightness). 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 point), 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 light sources that produce shorter wavelengths produce faster tests, there's a possibility of anomalous results if a tester has a wavelength cut-off below that of the material's end use environment.

Spectrum of Sunshine Carbon Arc. Figure 2 shows the UV SPD of summer sunlight compared to the SPD of a sunshine carbon arc (with Corex Dfilters). Note the large spike of energy, much greater than sunlight, at about 390 nm.

A more serious problem with the spectrum of the sunshine carbon arc is found in the short wavelengths. To illustrate this, a change of scale is necessary to expand the low end of the graph.

Figure 3 shows sunlight 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 realistic for outer space, but not at the earth's surface. These short wavelengths can cause unrealistic degradation when compared to natural exposures.

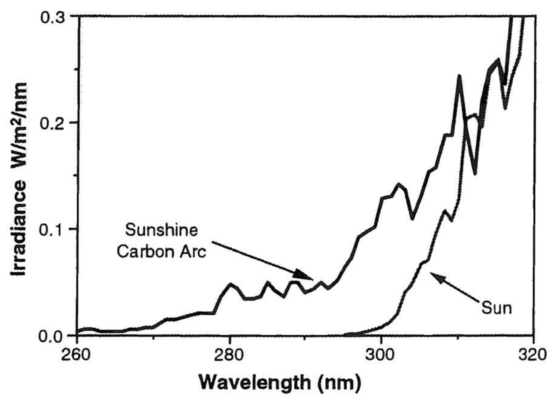

Figure 3 - Sunshine Carbon Arc and Sunlight

Sources of Variability in Carbon Arc Testing. Sunshine carbon arc testers utilize carbon rods which are "burned" to produce light. The carbons last for about 23 hours and have to be replaced daily. The total output and emission spectra may vary from one rod to another. This can create variability in results from short term tests. It may or may not cause problems for exposures that last several weeks, where the differences in output may be averaged out. A more important cause for variability in results from carbon arc testers is filter aging. Upon exposure to short wavelength UV light, carbon arc filters lose some of their ability to transmit light. A haze that is obvious to the naked eye builds up on the filter over time. In addition, smut from the combustion process is deposited on the filters and must be removed daily. Imperfect cleaning further contributes to a lack of uniform irradiance in carbon arc testers.

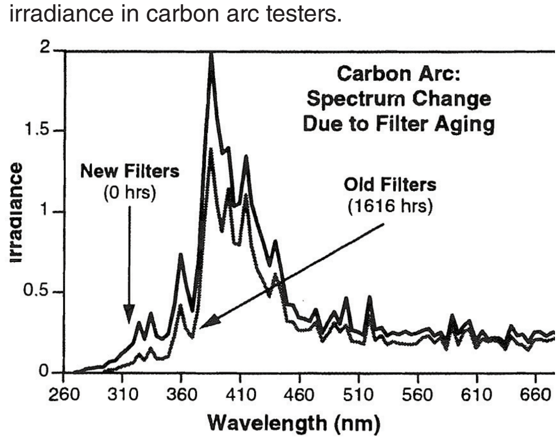

Figure 4 - Carbon Arc: Spectrum Change Due to Filter Aging

The change in transmission that occurs from solarization, hazing and smut is important throughout the longer visible portion of the spectrum, but it is especially significant in the shorter, more damaging UV wavelengths. Consequently, carbon arcs with new, unsolarized filters have a different SPD than testers with older filters. Figure 4 shows the SPD of a sunshine carbon arc measured with new Corex filters, compared to the same burner measured with older solarized and hazed filters.

Figure 5 shows the percent change in the spectrum between old and new filters. The drop in visible light output is about 20%. The change in the more damaging UV approaches 70°/. Changes of this magnitude will make significant differences in test results.

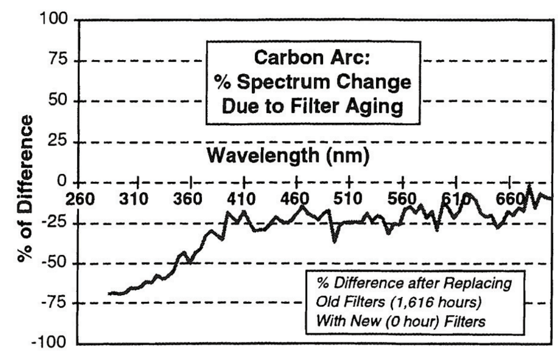

Figure 5 - Carbon Arc: % Change Due to Filter Aging

QUV Lamp Spectra

There are different types of QUV lamps, with different spectra, for different exposure applications. For further information see Q-Lab Bulletin LU-8160, Choice of Lamps.

UV-B Lamps. UV-B lamps are the most widely used QUV lamps. They have demonstrated good correlation to outdoor exposures for the gloss retention in coatings and for the material integrity of plastics. However their short wavelength output below the solar cut-off can occasionally cause anomalous results, especially for color retention of plastics and textile materials. The QUV accelerated weathering tester, with UV-B lamps, will generally give slightly faster test results than an sunshine carbon arc.

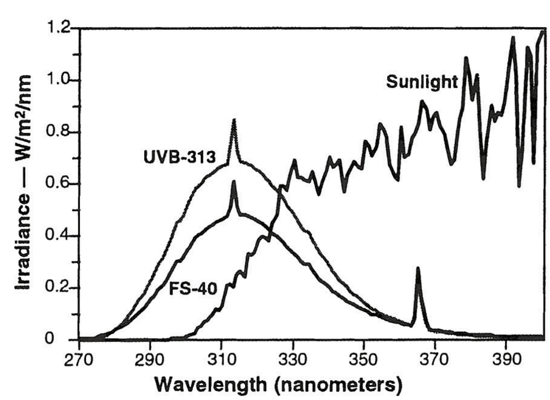

Figure 6 - UVB-313 and FS-40

UV-A Lamps. UV-A lamps were developed to enhance the correlation between QUV accelerated and outdoor testing. They usually give slower results than the UV-B, but are more realistic. UV-A lamps have been successfully used for testing plastics, textiles and coatings. Figure 7 shows the UVA-340 compared to Solar Maximum. This lamp is an excellent simulation of sunlight from about 365 nm, down to the solar cut- off of 295 nm.

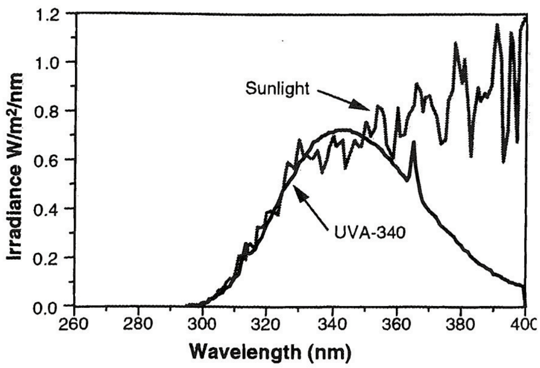

Figure 7 - UVA-340 and Sunlight

QUV Irradiance Control

The QUV tester uses fluorescent UV lamps to simulate the effects of sunlight. One advantage of fluorescent lamps is their spectral stability throughout their life. In other words, although fluorescent lamps loose output (i.e., brightness) as they age, their spectrum remains essentially the same. This consistency of spectrum allows easier control of irradiance.

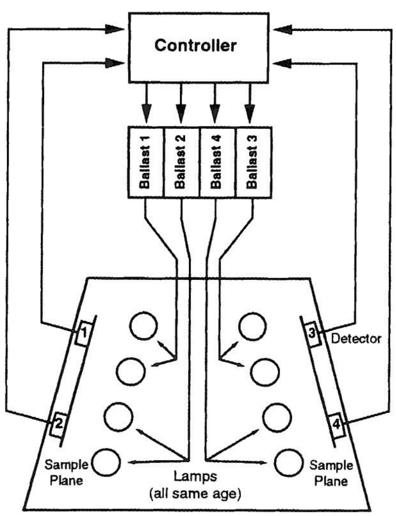

Figure 8 - SOLAR EYE Irradiance Control System

The QUV unit's SOLAR EYE® irradiance control system (models QUV/se and QUV/spray) 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 8 shows a simplified schematic of how the irradiance control system works. With the SOLAR EYE, the user sets the level of desired irradiance and the SOLAR EYE maintains it automatically. Each sensor monitors the intensity of two lamps. Each sensor is individually calibrated by the operator on a regular basis. The calibration is traceable to the U.S. National Institute of Standards and Technology (PI I ST). Unlike arc testers, fluorescent UV lamps degrade uniformly at all wavelengths during lamp aging. Consequently, there is no significant change in the spectral power distribution of the lamp. This is a great advantage for reproducibility. Figure 9 shows the percent change in spectrum due to lamp aging.

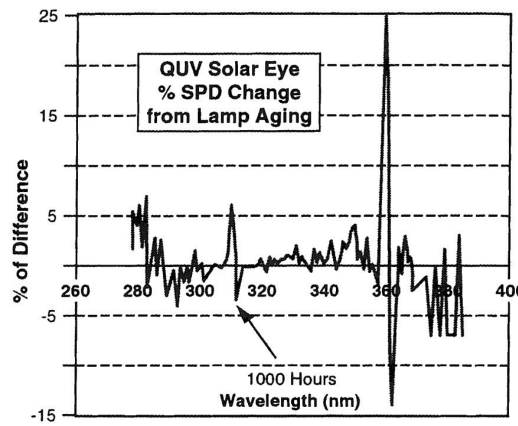

Figure 9 - UVB-313 2 Hrs. vs. 1000 Hrs.

Another advantage of the SOLAR EYE is that a push- button irradiance setting allows you to fix the exact irradiance level. With the UVA-340 lamp you can operate the SOLAR EYE at various levels for different applications and still maintain realistic test conditions. For example, as shown in Figure 10, with the UVA-340 lamps you could set the SOLAR EYE to simulate any of the following sunlight conditions:

- Intensified 75% (higher than QUV/basic) for fast results.
- Typical (equivalent to noon summer sunlight) for quick results without sacrificing correlation. This is the irradiance of a QUV/basic.
- Reduced to .35 W/m²/nm at 340 nm to match so-called "Average Optimum" sunlight or Xenon.

Using UVB-313 lamps, you can operate at Intensified (75% higher than standard) for extremely fast tests, for Quality Control applications, or for testing very durable materials. You can also set the irradiance level to be equivalent to the QFS-40 lamp and reap the benefits of greatly enhanced lamp life. (Figure 11)

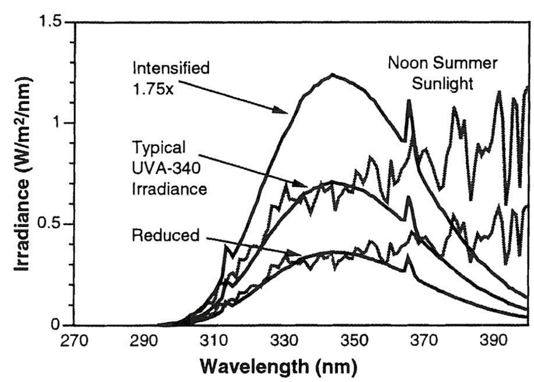

Figure 10 - UVA-340 Lamps vs Sunlight

The QUV/basic & Manual Irradiance Control

The QUV/basic is the original version of the QUV tester. It is still widely used in labs where economy is critical. It is the same as the QUV/se, but without the automatic SOLAR EYE irradiance control system. With the QUV/basic irradiance is not adjustable. The QUV/basic compensates for lamp aging by a simple rotation replacement system.

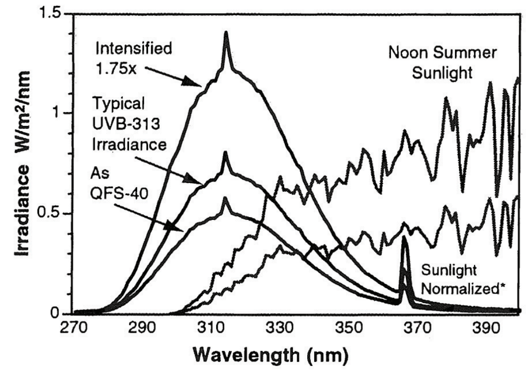

Figure 11 - UVB-313 Allow Fast Results

Rotation System. Each tester uses eight lamps; four on each side. Irradiance is controlled by replacing the oldest lamp in each bank every 400 hours of lamp operation. At that time the remaining six lamps are rotated as shown in Figure 12. The irradiance is an average of lamps at four different points on the age/output curve. This average remains relatively stable over time, giving these multi-lamp testers a substantial advantage over single lamp testers.

There are two inherent weaknesses in this system. First, there is no way to compensate for any lot to lot differences in lamps from manufacturing limitations. Second, because lamps deteriorate with age, there is a drop in light output between rotations. This is not significant with some lamp types. For example, UVA- 340 output drops only about 5%. However it can be very significant with other lamps. FS-40 lamp output may drop 15%.

Moisture Simulation

Sunshine Carbon Arc. The carbon arc uses a system of intermittent water spray to simulate the effects of rain and dew. There are several problems with this.

- Distilled or deionized water is necessary to prevent water spotting and contamination of the test specimen.
- Relatively cold water from a reservoir is sprayed on a hot sample. This causes thermal shock and rapid evaporation of the water. Moisture doesn't have time to penetrate the sample.
- Water from the reservoir may be oxygen poor.

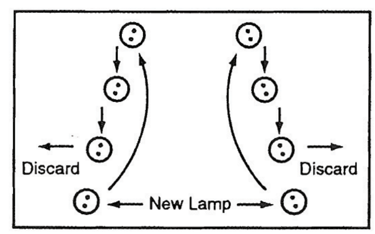

Figure 12 - Rotation/Replacement Sequence

QUV Tester Moisture System. The QUV tester uses condensation for it's moisture cycle. The QUV tester's condensation cycle is more realistic and more severe than water spray for the following reasons:

- Condensation simulates outdoor moisture attack more realistically than water spray. Most outdoor wetness is caused by dew, not rain. For more information on time of wetness outdoors, see Bulletin LU-0821, "Know your Enemy: The Weather and How to Reproduce it in the Laboratory."
- The QUV unit's condensation is at elevated temperature to accelerate moisture effects.
- The QUV tester allows the moisture several hours to penetrate the test specimen. A typical QUV tester condensation cycle is 4 hours at 50°C.
- The QUV machine's condensation assures water purity and oxygen saturation without cumbersome stills or deionizers.

Maintenance

The carbon arc requires daily cleaning and car- bon rod replacement. This procedure typically takes over an hour every day. Filters must be cleaned and replaced frequently. In contrast, QUV accelerated tester maintenance requirements are about 5 minutes each month. The QUV machine operates automatically over weekends and holidays, 24 hours a day, 7 days a week. This translates into significantly more yearly test time than a carbon arc.

Cost Considerations

Purchase Price. The purchase price of a carbon arc is many times higher than that of a QUV tester.
Operating Costs. Typical operating costs for an sunshine carbon arc in constant use are approximately $5,000 per year. The QUV costs about $1 000 per year if used continuously.

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