THE USE OF INTEGRATING SPHERES AS UNIFORM SOURCES FOR ACCELERATED UV WEATHERING OF ADVANCED MATERIALS

by

Joannie W. Chin, Jonathan Martin,
Edward Embree and Eric Byrd
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8621 USA

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Building Materials Division
National Institute of Standards and Technology
100 Bureau Drive, Stop 8621
Gaithersburg, MD 20899-8621

Introduction

Ultraviolet radiation exposure chambers are the primary means for generating laboratory weathering data for a wide range of commercial products including coatings, elastomers, plastics and polymer matrix composites. Over the years, numerous technical improvements have been implemented in the design, construction, and control of these UV chambers. However, the repeatability and reproducibility of the exposure results obtained from these chambers have remained elusive[1,2,3].

In this paper, a novel UV chamber based on integrating sphere technology is presented, which may be capable of reducing the magnitude of these systematic errors. In addition, it will be shown that the use of an integrating sphere-based UV chamber allows for greater flexibility in the design of weathering experiments.

Current Laboratory UV Weathering Instrumentation

Commercially available UV chambers began to appear circa 1920. Numerous modifications in the early UV chamber designs have been made over the last 80 years. These modifications have been aimed at improving the repeatability and reproducibility of exposure results and include the following:

- Identification of a more temporally stable ultraviolet light source.
- Identification of cut-off filter combinations to remove radiation below 290 nm.
- Identification of spectral radiant power distribution which more closely approximates the maximum solar ultraviolet radiant power [4,5].
- Re-design of the exposure racks within a chamber to improve the spatial irradiance uniformity over the dimensions of a specimen and between specimens.
- Introduction of photopic sensors and feedback-control devices for minimizing temporal changes in the radiant power [6,7].

These changes have greatly reduced the variability in exposure results, but have not fully resolved issues related to the lack of repeatability or reproducibility [2,3]. Common sources of systematic error found in current UV chambers include human/machine interactions, unnatural exposure conditions, non-uniform irradiance over the dimensions of a specimen and between specimens, the inability to accurately and precisely measure ultraviolet radiation dose, and temporal changes in exposure conditions. Of these sources of error, unnatural exposure conditions, non-uniform irradiance and temporal changes in exposure conditions have been targeted by NIST researchers as those which could be mitigated by the use of a novel integrating sphere-based UV chamber.

Integrating Sphere Theory

The theory of integrating spheres, as well as their uses in a wide variety of applications, is well-established [8,9]. An integrating sphere is basically a hollow spherical chamber with an inner surface coated with a diffuse reflecting, or *Lambertian*, coating. Light entering an integrating sphere undergoes multiple diffuse reflections at the interior surface, resulting in an uniform field of light within the sphere. This collected light can then serve as a means of measurement or as a source of uniform illumination. This latter capability is utilized in the novel UV weathering device.

Integrating Sphere Based UV Chamber

Integrating Sphere. NIST researchers are developing a UV chamber based on a 2 m diameter integrating sphere. A schematic representation of the NIST 2 m sphere is shown in Figure 1. The sphere construction is based on a modular panel design, which allows individual panels to be removed for modification or repair. The interior of the sphere is lined with PTFE panels, and currently contains thirty-two 11.2 cm diameter ports. A 61 cm diameter top port accommodates a high intensity UV light source.

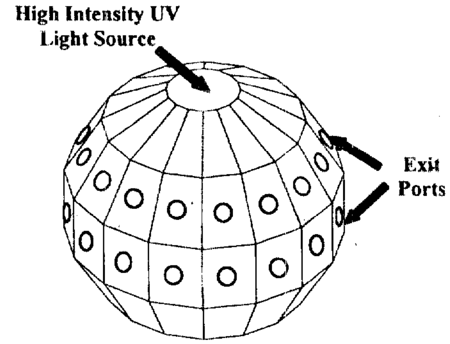

Figure 1. Schematic representation of NIST 2 m integrating sphere.

UV Lamp System. The lamp system utilized with the 2 m sphere is a microwave-powered, electrodeless lamp system with an output that is rich in the region between 290 nm and 400 nm. Dichroic reflectors in the lamp housings remove (80-90) % of the infrared and visible output from the lamps, allowing UV radiation effects to be isolated from temperature effects, if desired. In addition to removing the infrared and visible radiation, radiation below 290 nm can also be removed from the radiant flux by positioning a cut-off filter after the dichroic mirror. Moreover, interference or cut-off filters can be positioned in front of each specimen so that each specimen can be uniquely irradiated using any combination of wavelengths.

A multiple lamp system is utilized, which has been calculated to provide an irradiance level greater than 30 suns (where a "sun" is defined as the integrated irradiance between 305 nm and 400 nm taken from the direct normal spectral solar irradiance distribution in ASTM G159). Use of multiple lamps allows the response of a material to various irradiance levels to be evaluated, which in turn provides a test of the law of reciprocity.

Sphere Output. Due to the fact that every point on the integrating sphere surface is theoretically equivalent to every other point, the monitoring of UV spectral intensity is quite simple. For instance, a fiber optic probe could be inserted at an arbitrary point in the sphere wall (away from the "first strike" region of the light source) and connected to a spectroradiometer to provide a measure of the spectral radiance within the sphere. Through photofeedback processing, lamp power can be continually adjusted to compensate for temporal instabilities in and diminishment of lamp output over time.

Prior to the design and fabrication of the 2 m integrating sphere, a prototype 50.8 cm diameter sphere was utilized to determine the suitability of integrating spheres for use in artificial weathering devices. Spectral UV measurements were made in the center of two 12.7 cm diameter apertures of this sphere, one on the right side of the sphere and the other on the left. Spectral output for a 1000 W xenon arc source are overlaid in Figure 2. No discernible difference between the two spectra was observed. Spectral UV

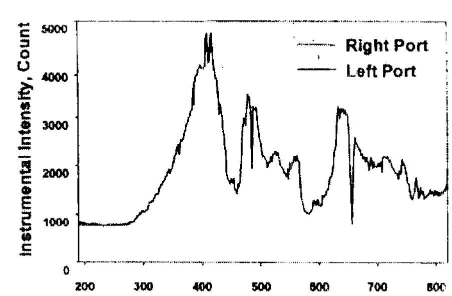

Figure 2. Comparison of spectral output from right and left exit ports on a 50.8 cm integrating sphere.

intensity was also mapped over the entire port area by taking 33 separate measurements across the plane of the port. As seen in Figure 3, all 33 spectra overlay each other, implying a high degree of irradiance uniformity over the plane of the port.

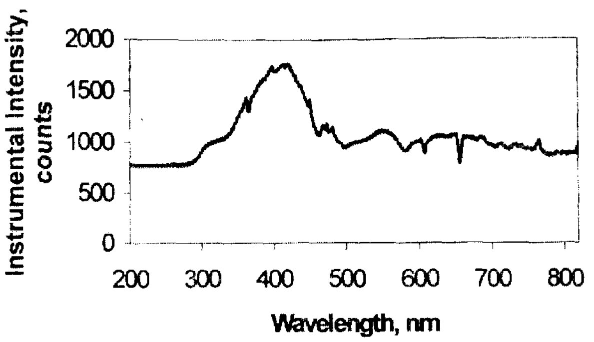

Figure 3. Comparison of spectral output taken over 33 different points on the exit port of a 50.8 cm integrating sphere.

Exposure Chambers. In order to assess the environmental durability of materials used in building and construction applications, it would be advantageous to uniformly irradiate specimens under a variety of conditions. This could be accomplished with the integrating sphere-based UV device by equipping each port with a exposure chamber in which temperature, relative humidity, mechanical loading and other factors can be independently controlled.

Because each chamber is independent of the others, a multiplicity of environmental conditions can be evaluated in a given experiment. While the UV irradiance is identical for each individual port, narrow band-pass filters or neutral density filters can be installed at the exit port to study the effect of a narrow wavelength region or to adjust the intensity, respectively. For instance, it would be possible to expose a specimen at one exit port to 60 °C, 95 % relative humidity, polychromatic light; whereas, at another exit port, the specimen could be exposed to 50 °C, 95 % relative humidity, and 290 nm radiation. The capability to subject specimens to mechanical loading while they are undergoing UV exposure can also be achieved, as shown in Figure 4. Other unique exposure environments can also be created, including freeze/thaw cycling and acid rain.

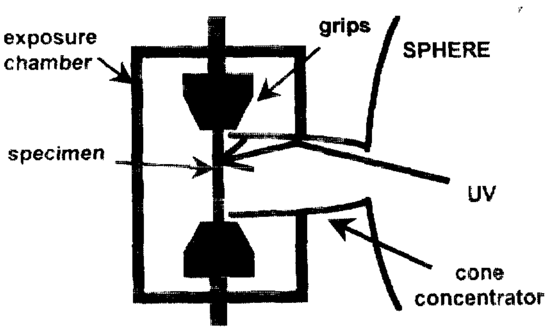

Figure 4. Proposed exposure chamber with capability for specimen loading.

Due to the physical space taken up by the loading frame and the specimen grips, non-imaging optical devices, also known as compound parabolic concentrators, Winston cones and cone concentrators, will be used to convey the highly uniform radiation from the sphere exit ports to the exposure chambers (see Figure 4). These devices, which date back to the 1960's and were once used for solar collection, are considered to be more efficient than conventional image-forming optics in concentrating and collecting light (for a detailed treatment, see reference 10). In this application, they will be used to collimate the diffuse output from the sphere exit port to within 20 ° ± 3 ° and transfer it to the specimen surface with minimal loss in intensity and irradiance uniformity.

Summary

UV chambers play an important role in comparing and predicting the performance of construction materials and determining the effect of different weathering factors on the performance of a construction material. Although significant modifications have been made in current UV chamber designs, controlling the systematic errors and thus the repeatability and reproducibility of these chambers has remained elusive. An integrating sphere UV chamber design is being developed which is expected to mitigate known sources of systematic error. Assuming that the sphere is properly designed and that the UV lamps are correctly integrated, the irradiance provided by an integrating sphere-based UV chamber is extremely uniform across the dimensions of a specimen and between specimens. This uniformity is independent of the specific lamp type, age of the lamp or any manufacturing variations present in the lamp. In addition, use of an integrating sphere provides the opportunity to simultaneously and independently expose a multiplicity of specimens in separate exposure chambers, in which the environmental and operating conditions within each chamber can be uniquely selected. This objective can be achieved by positioning specimens in individual exposure cells and uniformly irradiating the specimens by projecting the output from the sphere exit ports by using non-imaging optical devices.

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