UV dosimeter based on Polyphenylene Oxide for the measurement of UV exposures to plants and humans over extended periods

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Abstract

Long-term solar UV measurements made by Poly (2, 6-dimethyl-1, 4-phenylene oxide) (PPO) dosimeters with a polyethylene neutral density filter (NDF) are presented in this manuscript. These measurements show that the life span of a PPO dosimeter can be effectively doubled before saturation. Therefore, as the dynamic range of PPO film is known to be approximately seven days during summer at a sub-tropical location, the advantage of using a NDF is that half the number of dosimeters will be required to be prepared and analysed before and after solar exposure. In addition, this manuscript depicts how the spectral response of the PPO dosimeter closely resembles the erythemal response and how the PPO dose response varies in accordance to changes of the solar spectrum resulting from seasonal changes and atmospheric ozone.

Introduction

Thin films based on Poly (2, 6-dimethyl-1, 4-phenylene oxide) (PPO) have been previously developed for use as UV dosimeters (Berre and Lala, 1989). More recent research has characterised the properties of PPO for use as a UV dosimeter to measure long–term erythemal and UVB exposures to humans, in aquatic environments and to plants (Schouten *et al*., 2007; 2008; 2009; 2010; Parisi *et al*., 2010; Lester *et al*., 2003). The advantage of using PPO as a dosimetric material is that its dynamic range is approximately seven times longer than that of polysulphone. This allows for the measurement of long-term exposures without the daily need to change the dosimeters in the field. Furthermore, this extended dynamic range can be doubled through the use of a neutral density filter (NDF) (Schouten *et al*., 2010). This paper will report on the spectral response of PPO, the variation in the unfiltered PPO calibration and the extension of the PPO dynamic range with the use of a NDF.

Spectral Response

The thin PPO film was produced at a thickness of 40 μm at the University of Southern Queensland, cut into pieces and mounted onto 3.0 x 3.0 cm thin PVC holders, each with a 1.6 x 1.2 cm central aperture to produce dosimeters. The UV induced change in the property of the PPO film to allow use as a UV dosimeter is the change in optical absorbance which is measured at 320 nm in a spectrophotometer (model UV1601, Shimadzu Co., Kyoto, Japan).

The spectral response in Figure 1 was determined by employing a 1600 W irradiation monochromator (model 66870, Oriel Instruments, USA) to expose the dosimeters with a series of measured monochromatic wavelengths with measurement of the change in absorbance of the material.

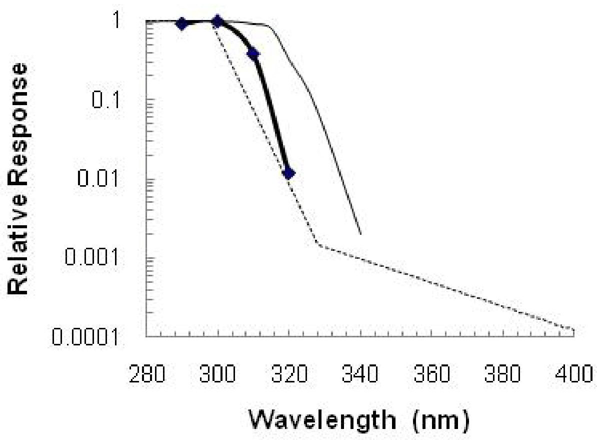

Figure 1. Spectral response of 40 μm PPO dosimeter film (thick line) compared to the erythemal action spectrum (CIE, 1987) (dashed line) and the polysulphone spectral response (CIE, 1992) (thin line).

Unfiltered Calibration and Dose Response

Unfiltered calibrations of the PPO dosimeters were performed at the sub-tropical site of the University of Southern Queensland campus in Toowoomba, Australia (27.5^{o} S, 151.9^{o} E, 693 m altitude) from March 2007 to February 2008. The cumulative erythemal exposures were measured with an erythemal UV meter (model 501, Solar Light Co. PA, USA) calibrated to a spectroradiometer system (Bentham Instruments, Reading, UK) with calibration traceable to the National Physical Laboratory (NPL).

Figure 2 displays seasonal PPO calibration regimes and also compares the dynamic range of the PPO dosimeter to that of a polysulphone dosimeter calibrated in summer. From Figure 2 it can clearly be seen that the response of the PPO dosimeter varies substantially from season to season. In order to eliminate the introduction of any critical errors in field solar exposure measurements caused by seasonal variations in solar zenith angle (SZA) along with varying column ozone trends, calibrations are required to be performed with respect to the source spectrum that they will be measuring in order to take into account the changes in the solar spectra.

In Figure 2 it can be seen how the dynamic range of the PPO dosimeter far exceeds that of the polysulphone dosimeter before approaching saturation. A direct comparison between the summer polysulphone calibration and the summer PPO calibration shows that the PPO dosimeter offers close to seven times more solar exposure time than the polysulphone dosimeter. This equates to an extra dosage of approximately 164 SED (Standard Erythemal Dose).

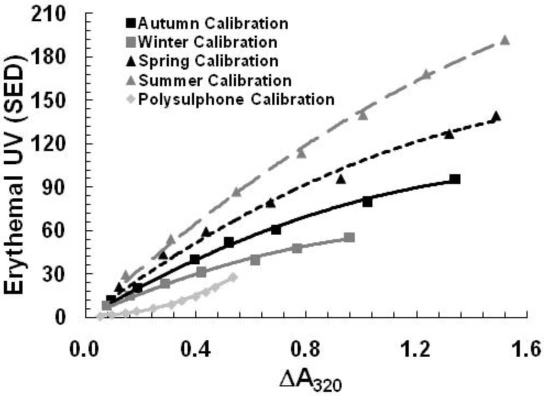

Figure 2. Calibration of PPO in each of the four seasons compared to a polysulphone calibration.

Dynamic range extension

Polyethylene was employed as the NDF material taped over the PPO dosimeter to extend the dynamic range. This material has a reasonably flat transmission in the UV waveband of interest. This attribute is desirable as it allows for equal amounts of solar energy to pass through to the dosimeter at each wavelength, which leads to the reduction of measurement uncertainty that could result from variations in the incident solar UV spectra.

The transmission spectrum of the NDF measured in the spectrophotometer is in Figure 3 before and after exposure to 450 SED. Although there is a drop in transmission by approximately 4% after exposure, this is taken into account during the calibration of the extended dynamic range dosimeters.

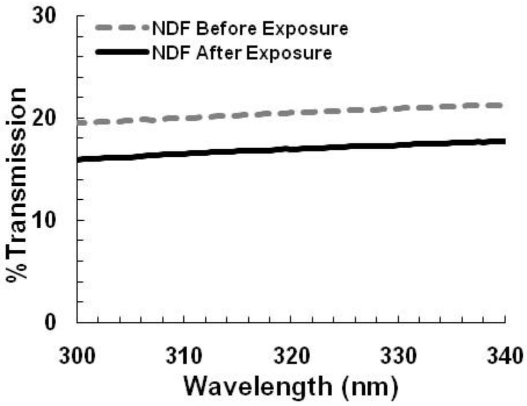

Figure 3. Transmission of the NDF before and after exposure to 450 SED.

Figure 4 displays an erythemal UV calibration obtained with the NDF attached to a batch of PPO dosimeters in autumn 2008. As was the case with the unfiltered PPO dosimeters, this calibration was performed at the University of Southern Queensland Toowoomba campus using the same solar UV measurement equipment. With the use of the NDF, the incoming UV wavelengths are attenuated which changes their spectral energy distribution that in turn affects the response of the dosimeter underneath. Consequently, the PPO dosimeter must be calibrated for long-term field use with an NDF attached to it. This will also take into account any short and long-term variations in the absorption characteristics of the NDF material.

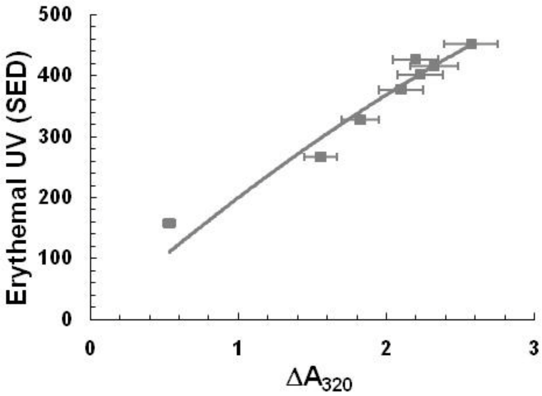

Figure 4. Calibration of PPO with the NDF.

Discussion

A UV dosimeter based on PPO thin film has been described. The dynamic range compared to polysulphone is longer by a factor of approximately seven. This allows erythemal UV measurements up to 192 SED before optical saturation. This equates to up to a week of exposure time on a horizontal plane at a sub-tropical site. This dynamic range is further extended with the use of an NDF to allow erythemal UV measurements up to 452 SED.

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