Results in Physics 7 (2017) 1492–1493

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.journals.elsevier.com/results-in-physics

Microarticle

Measuring diffuse ultraviolet exposures using Gafchromic EBT3 films

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ARTICLE INFO

Article history:
Received 14 January 2017
Received in revised form 14 April 2017
Accepted 14 April 2017
Available online 21 April 2017

Keywords:
Radiochromic film
EBT3 film
Ultraviolet exposures
Overhangs

ABSTRACT

The present work proposed to use Gafchromic EBT3 films for determining spatial variations of ultraviolet (UV) exposures in the environment, which required many simultaneous measurements, and demonstrated the feasibility by showing the variation of the diffuse component of solar (UVA + UVB) exposures (in $\mathrm{Jcm^{-2}}$) in shaded areas under overhangs with the elevation angle θ for the edge of the overhangs.

Introduction

The solar ultraviolet (UV) radiation arriving at the surface of the Earth consists of mainly UVA (315–400 nm) and a small amount of UVB (280–315 nm), and comprises a direct component and a diffuse component. The diffuse component refers to the portion which has been scattered in the atmosphere, and scattered and reflected from the ground and surrounding objects. The direct component directly comes from the sun. Knowledge on spatial variations of UV exposures in the environment is important both for understanding the physical processes involved and for the assessment of associated health hazards, but experiments have been formidable due to requirements of many simultaneous measurements and lack of economical measurement devices. The present work proposed to use EBT3 radiochromic films [6] for such measurements, and demonstrated the feasibility by studying variations in the diffuse component of UV exposures (in $\mathrm{Jcm^{-2}}$) in shaded areas under overhangs. The erythemal action spectrum was not needed since it was not an objective of the present work to assess the health hazards of UVA or UVB. The EBT3 film was more convenient than other radiochromic films such as the polyphenylene oxide film and the polysulfone film in that the color changes in the EBT3 film occur in the optical region while those in other films occur in the UV region. Another advantage was that the EBT3 film was commercially available.

Materials and methods

Radiochromic films were originally designed for quantifying clinical X-ray doses [4] through their color changes, and later adopted for quantifying X-ray doses in radiobiological experiments [5]. Chun and Yu [6] established procedures in using the EBT3 film for characterizing solar (UVA + UVB) exposures. Butson et al. [2] confirmed that the EBT film was insensitive to visible light, so the EBT3 film as the successor of EBT film having the same active components could characterize UV exposures alone. Aydarous et al. [1] showed that the EBT3 film had same responses to UVA and UVB. ISP Gafchromic EBT3 films (Lot No. A03181301) were employed in the present study. Each exposed film had a size of $1.5 \times 1.5\ \mathrm{cm^2}$ and was supported by a black polypropylene (PP) film (Easy Mate Black PP Cover Sheet PH29721040BK). Following UV exposures, the films were transferred into light tight containers kept under constant temperature and relative humidity. After 24 h, the central parts of the films with an area of $0.75 \times 0.75\ \mathrm{cm^2}$ were scanned using an Epson Perfection V700 desktop flatbed scanner set in the reflection mode with a resolution of 50 dots per inch (dpi) [6] to obtain 48-bit RGB color images. The red component of the images was analyzed using ImageJ which could be freely downloaded from the website: http://imagej.nih.gov/ij/. Changes in color of the UV-exposed films were defined by the net reflective optical density (*Net ROD*) expressed as *Net ROD* = log (P_u/P_t) where P_u and P_t were the pixel values generated by scanning the unexposed and exposed films, respectively [2]. The orientation of films should be consistent as a change would affect the measured ROD [3]. Calibration procedures followed those described by Chun and Yu [6].

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http://dx.doi.org/10.1016/j.rinp.2017.04.016
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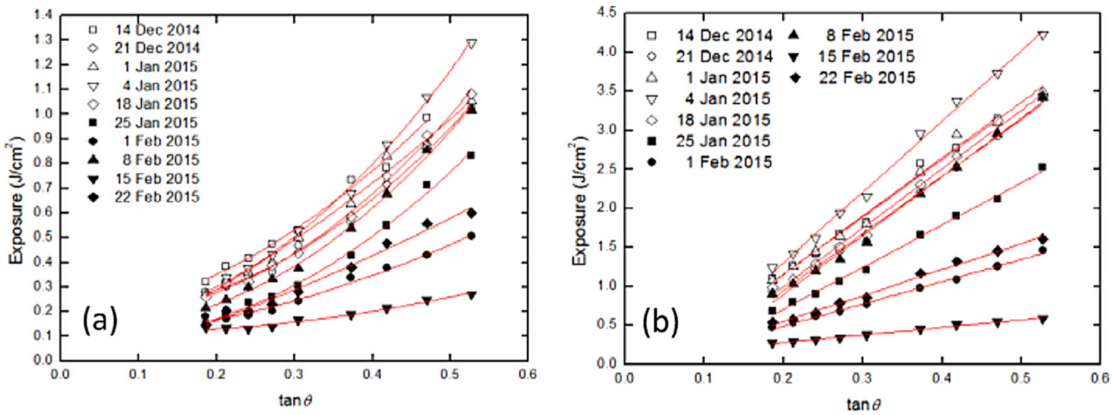

Fig. 1. Variation of UV exposures (J/cm^2) at AC3 site with tanθ, where θ was the elevation angle of the edge of the overhang: (a) UV exposures measured using horizontal EBT3 films, and data fitted using 2nd order polynomial functions (red lines); (b) UV exposures measured using vertical EBT3 films, and data fitted with straight lines (red lines). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

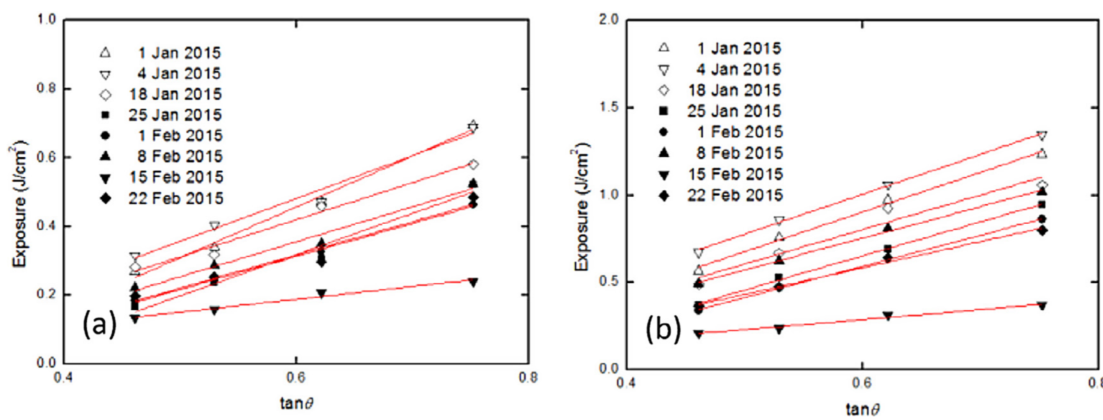

Fig. 2. Variation of UV exposures (J/cm^2) at GC site with tanθ, where θ was the elevation angle of the edge of the overhang. UV exposures measured using EBT3 films placed (a) horizontally and (b) vertically, and data fitted with straight lines (red lines). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Diffuse solar (UVA + UVB) exposures were measured from December 2014 to February 2015 on the campus of City University of Hong Kong in (1) the covered podium of the Academic Building 3 (AC3), and (2) the covered seating area of the Garden Café (GC). The measurements lasted 5 h (from 10 am to 3 pm) on Sundays and public holidays to minimize the effects caused by human activities. The noon solar zenith angles on 1 December 2014, 1 January 2015 and 1 February 2015 were 44.1°, 45.7° and 40.5°, respectively. For each measurement position, one film was placed horizontally and the other one was erected vertically. The angle of elevation θ for the edge of an overhang at each measurement position was given by tan$\theta = y/x$ where y was the vertical distance between overhang edge and measured point determined using the HILTI PD40 laser range meter (Hilti Corporation, Schaan, Principality of Liechtenstein) with an accuracy ± 1 mm, while x was the horizontal distance between overhang edge and measured point measured using a measuring tape with an accuracy ± 0.5 mm.

Results and discussion

The response of the EBT3 film was found as *Net ROD* = −0.00995 + 0.483/{1 + 10[0.969(0.387−log(*Exposure*))]} with R^2 = 0.998. The variations in UV exposures (J/cm^2) at AC3 and GC with tanθ are shown in Figs. 1 and 2, respectively. The UV exposure increased under sunnier conditions with less cloud cover. The AC3 data measured with horizontal EBT3 films could not be fitted with straight lines (but were satisfactorily fitted using 2nd order polynomial functions giving R^2 values in the range from 0.98 to 1.00), while all other data could be satisfactorily fitted with straight lines giving R^2 values in the range from 0.92 to 1.00. The present study showed the feasibility of using EBT3 films to determine spatial variations of UV exposures in the environment, but further experiments would be needed to give a more complete picture and to provide data for understanding the physical processes involved and for assessment of associated health hazards.

Acknowledgment

This work was supported by a General Research Fund CityU 125013 from the Research Grants Council of the Hong SAR.

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