Temperature effects of PTFE diffusers

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Abstract. Poly(tetrafluoroethylene) (PTFE) is the most commonly used diffuser material in ultraviolet irradiance measurements. The temperature sensitivities of five PTFE diffusers were measured over a broad temperature range. The transmittance change varied from -0.015%/°C to -0.1%/°C. At 19°C there was an unexpected abrupt change in transmittance ranging from 1% to 3%. This change is due to the change of the crystal structure of PTFE at 19°C. Temperature sensitivity decreases significantly the accuracy of high precision measurements, especially if the temperature of the diffusers is not stabilized.

Introduction

In optical radiation measurements diffusers are used for input optics in order to achieve a uniform spatial responsivity and a specific angular response, i.e. cosine response in irradiance measurements. In ultraviolet (UV) measurements the most commonly used diffuser material is poly(tetrafluoroethylene), PTFE. PTFE is better known by trade name Teflon®. PTFE has good chemical resistance, it is light- and weather-resistant and has no absorption of water. These properties make PTFE an attractive material for outdoor use.

The effect of temperature on the UV-transmittance of five PTFE diffusers and one quartz diffuser was examined [Ylianttila and Schreder, 2005].

Materials and methods

The temperature sensitivities of six different diffusers were tested. One of the diffusers was a quartz diffuser, so that the effect of the temperature change on the PTFE diffuser and on the fiber-end could be distinguished. The tested diffusers included three Schreder UV-J1002 and UV-J1003 type PTFE diffusers [Schreder et. al., 1999], a standard PTFE plane diffuser of a Bentham DM 150 spectroradiometer, a PTFE dome diffuser of an Optronic 742 spectroradiometer and a a quartz diffuser of an Optronic 742 spectroradiometer. The Schreder UV-J1002 and UV-J1003 diffusers have the same diffuser material and design. Due to the similarity they are from now on addressed as Schreder J1002 diffusers. They were also the only diffusers with a protective quartz dome. The thickness of the PTFE layer in the diffusers varied, the Optronic dome diffuser was the thinnest; 0.2 mm, the standard plane diffuser was 0.6 mm thick and the thickness of the Schreder J1002 diffuser was approx. 2.5 mm. The majority of tests were made with the Schreder J1002 diffuser (both STUK and CMS) and the other diffusers were tested to obtain additional data for comparison.

The experiment was done by controlling the temperature of the diffuser and measuring a stable reference lamp. The changes in transmittance were obtained by comparing the lamp measurements to the measurements done at reference temperature. A more detailed description of the test set-up is presented in [Ylianttila and Schreder, 2005].

Results

The transmittance change as a function of temperature from all Schreder J1002 tests is presented in figure 1. The transmittance is normalized to 1 at 26°C. The wavelength used in the measurements is 400 nm, except for the first CMS measurements, which were made at 320 nm. The transmittance of the Schreder J1002 diffuser decreased by 0.1%/°C (1%/10°C) when the temperature was increased. At 19°C there was a sudden change of 3% in the transmittance. There was some spread (± 1°C) in the transition temperature and there could be some hysteresis in the exact position of the transition temperature.

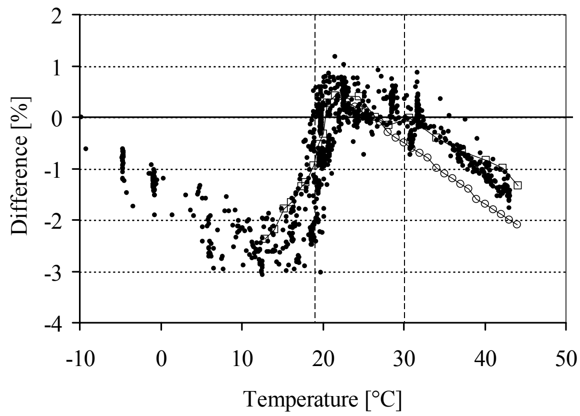
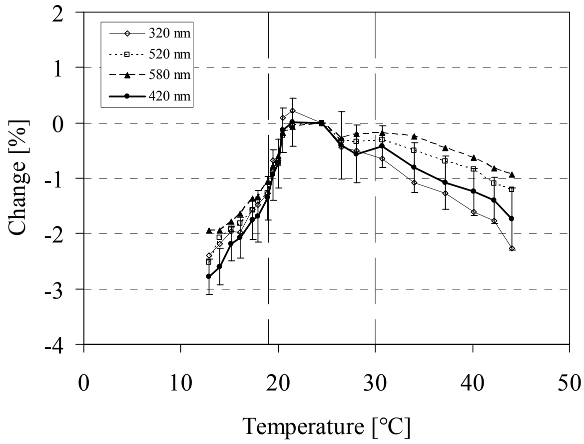


Figure 1. The change of transmittance of the Schreder J1002 PTFE diffuser as a function of temperature. The measurements done at CMS are those connected by the thin line. The transmittance is normalized to 1 at 26°C. The phase shift temperatures of PTFE are marked as vertical dashed lines.

At CMS the measurements were made with a wider wavelength range of 280 nm - 600 nm. The transmittance change at different wavelengths is presented in figure 2. The results have been normalized at 24.5°C. The 420 nm data have also the error bars (1σ) drawn. Below 27°C only minimal wavelength dependency can be seen. Above 27°C there is a slight wavelength dependency. No wavelength dependency could be distinguished from the measurements made at STUK due to the smaller wavelength range (300 nm - 400 nm).

Figure 2. The change of transmittance of the Schreder J1002



PTFE diffuser for different wavelengths. The error bars (1σ) are given for the 420 nm data. At temperatures above 27°C a clear wavelength depending difference can be seen.

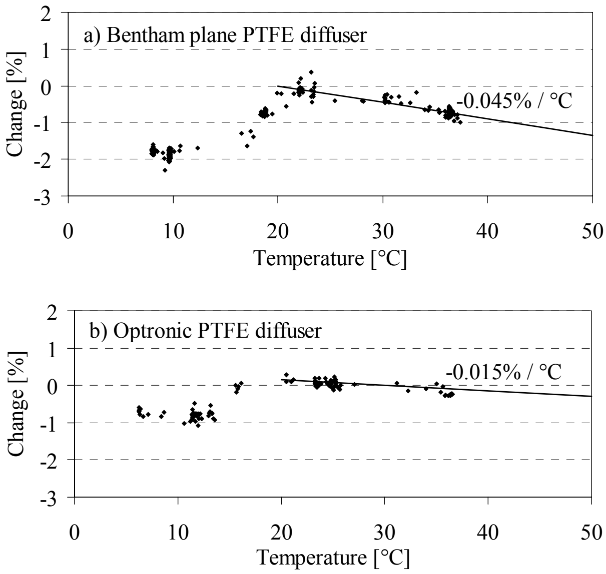


Figure 3. The transmittance change of a Bentham plane PTFE diffuser and Optronic PTFE diffuser.

The temperature response was similar with the other PTFE diffusers as can be seen in figure 3. The effects of temperature change were slightly smaller; the transmittance decreased by 0.045%/°C (1%/22°C) and the transmittance change at 19°C was 2%. The Optronic 742's PTFE diffuser had the smallest temperature sensitivity of PTFE diffusers; the transmittance decreased only by 0.015%/°C (1%/66°C) and the transmittance changed only by 1% at 19°C. The quartz diffuser had a different temperature response; the transmittance increased by 0.035%/°C (1%/33°C) and there were no sudden changes in transmittance in this temperature range.

Discussion

The drastic change in transmittance at 19°C is due to the properties of PTFE. The crystal structure of PTFE changes from phase II to phase IV at 19°C [Clark 1999, Briscoe et. al. 2003, Yamamoto and Hara, 1986]. This change has an influence e.g. in the density and the thermal expansion coefficient of PTFE. PTFE has another crystal structure change from phase IV to phase I at 30°C, but there was no clear change in transmittance at this temperature. The absence of the transmittance change at 19°C in the quartz diffuser measurement shows that the transmittance change is not coming from the quartz fibre.

The thickness of the PTFE layer seems to increase the temperature effects. With the thin Optronic 742 diffuser both the abrupt change at 19°C and the linear change of transmittance as a function of temperature are much smaller than with the thicker Schreder J1002 diffuser. A reason for this could be that the phase shift changes the absorbance or diffuse propagation properties of PTFE. Another reason for the difference could be the type of PTFE used in the diffusers. Different materials can be inserted into PTFE to change its properties, e.g. wear resistance. The exact type of PTFE used in the tested diffusers is not known.

These results strongly suggest that, when a PTFE diffuser's temperature is near 19°C, the measurement uncertainty is increased. In a temperature regulated laboratory room this is hardly a problem, as the ambient room temperature is usually kept above 20°C. In outdoor measurements, especially in the monitoring of solar UV radiation, ambient temperatures of 19°C can't be avoided. One option is to characterize the temperature effect of the diffuser and monitor the temperature of the diffuser and correct the measurement data accordingly. The possible temperature difference between the PTFE diffuser and the temperature sensor (the temperature sensor can't be attached directly to the optical part of the diffuser) and small temperature drifts near the transition temperature 19°C would still be problematic. The other option is to stabilize the temperature of the diffuser. By setting the stabilization temperature above ambient temperature, the condensation of water into the surface of the diffuser is also prevented.

The effect of the temperature sensitivity of PTFE diffusers have been detected in sky measurements in optimum conditions [McKenzie et. al., 2005]. Therefore the diffuser has to be temperature stabilized and the temperature has to be monitored, if the uncertainty of solar UV measurements is required to stay within the state of the art limits (± 5%).

References

Briscoe, B.J., H. Mahgerefteh, and S. Suga, The effect of gamma irradiation on the pressure dependence of the room temperature transition in PTFE, *Polymer, 44*, 783-791, 2003.

Clark E.S., The molecular conformations of polytetrafluoroethylene: forms II and IV, *Polymer, 40,* 4659-4665, 1999.

McKenzie, R., J. Badosa, M. Kotkamp, and P. Johnson, Effects of the temperature dependency in PTFE diffusers on observed UV irradiances, *Geophys. Res. Lett., 32,* L06808, 2005.

Schreder, J., M. Blumthaler and M. Huber, Design of an input opticfor solar UV-measurements, Internet Photochemistry & Photobiology, Issue: Protection against the hazards of UV, http://www.photobiology.com/UVR98/index.htm, 1999.

Yamamoto, T. and T. Hara, X-ray and Monte Carlo studies on the 19°C transition of poly(tetrafluoroethylene), *Polymer, 27*, 986-992, 1986.

Ylianttila, L. and J. Schreder, Temperature effects of PTFE diffusers, *Opt. Mater.*, in press.