Technical Note: Need for a "Normalization" Correction for Cosine Emitter UV Irradiance Models

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INTRODUCTION

The Cosine emitter UV irradiance (fluence rate) models usually used for UV reactor modeling do not incorporate the correct power output per unit emitter. The Cosine model must be modified by a factor of 4/π, as outlined in the discussion below.

RATIONALE

The simplest model that has been used to model UV lamps is the Point Source model, which has been used in discrete and in integral form. For each source element, the Point Source model takes the lamp power, *P*, per unit length, *L*, multiplies by a differential or discrete length, *dx*, and radiates this power uniformly in all directions. At radius *r* the fluence rate, *F*, from the element is therefore

$$F(r) = \frac{P}{4\pi L r^2} dx$$

In order to improve the accuracy of the spatial distribution from this model, various authors have incorporated a Cosine function, so that each differential element has the following distribution:

$$F(r,\theta) = \frac{P\cos(\theta)}{4\pi L r^2} dx$$

This is incorrect because the total power emitted is less than *P/L dx*, since the normal component is unchanged from the Point Source model but all other components have been multiplied by cos *θ*, a factor less than unity.

The correct form of the equation can be determined by integrating irradiance over an enclosing spherical surface and requiring that the result be equal to the enclosed power (applying the divergence theorem). It can be shown that the correct equation is

$$F(r,\theta) = \frac{P\cos(\theta)}{\pi^2 L r^2} dx$$

The normal component in this equation is greater than that in the simpler Point Source and the more common Cosine/Lambertian model by a factor of 4/π. The integrated power is *P/L dx*.

Recent versions of some software use the incorrect equation. This can be confirmed by determining the fluence rate at a series of points on a sphere enclosing a lamp and integrating the irradiance over this closed volume. It can be seen that the resulting integral is less than the lamp power by the factor π/4.

With this new correct form, the Cosine model agrees well with goniometric measurements of lamp output taken in three different laboratories in three countries (to be published separately). The author recommends that investigators incorporate this factor of 4/π into future modeling.

COMMENT

(From Dr. James Bolton, Bolton Photosciences Inc., 628 Cheriton Cres., NW, Edmonton, AB, Canada T6R 2M5)

I agree with the need for the correction proposed by Mike Sasges, but it is needed only in cases where the lamp efficiency is determined by using the 4π solid angle integration protocol introduced by Sasges and Robinson (2005). In cases where the lamp efficiency is estimated by matching the model prediction to a measured irradiance at a certain distance (e.g., see Rahn et al. 2006), a correction is not necessary for extrapolation to irradiance at other distances, but the lamp power will be incorrect by the stated factor.

REFERENCES

Rahn, R.O., Bolton, J. and Stefan, M. 2006. The Iodide/Iodate Actinometer in UV Disinfection: Determination of the Fluence Rate Distribution in UV Reactors, Photochem. Photobiol., 82(2): 611-615.

Sasges, M. and Robinson, J. 2005. Accurate Measurement of UV Lamp Output, IUVA News, 7(3): 21-25.