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SELF-ABSORPTION EFFECT IN MEASUREMENTS OF LAMPS LUMINOUS FLUX

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ABSTRACT

In this work, the effect of self-absorption on the lamps' luminous flux measurements at the NIS-Egypt integrating sphere facility has been studied. With integrating sphere photometry comes errors from self-absorption. Industry standards recommend applying absorption correction techniques for situations where the physical configuration and characteristics of the lamp or LED under test differ from the reference lamp. Self-absorption correction is critical since the physical size and shape of SSL products and lamps under test are typically very different from the reference lamp size and shape. In our study, different groups of lamps under test are used to determine it's luminous flux as well as the self-absorption factor; High-Pressure Sodium (HPS), High-Pressure Mercury (HPM), Metal Halide (MH), Double-Ended Halogen (DE), Compact (C1, C2, C3) and LED (W1, W2, W3). Results show that the self-absorption factor has a considerable effect that can reach up to 7% on the measurements of total luminous flux such as in (DE) lamps. This effect must be considered and added to the measured luminous flux as a correction. Unless the test lamps are the same type as the standard lamps, the self-absorption should be measured and corrected.

Keywords: self-absorption factor, luminous Flux, integrating sphere, photometry.

1. INTRODUCTION

A lamp in the sphere absorbs light emitted by itself and reflected from the sphere wall, thus reducing the sphere responsivity. This effect is called self-absorption. It is defined as the effect, in which the responsivity of the sphere system changes due to the absorption of light by the lamp itself in the sphere. If the size and shape of the test light source varies from those of the standard light source, errors may arise. Because the physical size and shape of the SSL products under test are often quite different from the reference standard size and shape, the self-absorption correction is crucial. Because the sphere coating's spectral reflectance is not spectrally flat, the self-absorption is wavelength-dependent. The more absorption the lamp exhibits, the larger the lamp and the darker the colour of the lamp [1, 2].

For self-absorption measurement, the integrating sphere must be supplied with an auxiliary lamp. A sphere-spectroradiometer system's auxiliary light must provide broadband radiation across the whole spectral range of the spectroradiometer. Thus, a quartz halogen lamp is typically used for this purpose. Throughout the self-absorption tests, the auxiliary lamp light output must remain constant. It should be noted, however, that as the reflectance of the sphere increases, it becomes more susceptible to self-absorption effects and long-term drift, as well as having more spectral throughput variation [3-5]. The auxiliary lamp for a sphere-photometer system does not have to be an incandescent lamp. Rather, it is preferable to use an auxiliary lamp with a spectral distribution similar to that of the SSL products typically measured, in order to accurately measure self-absorption, particularly when the self-absorption is very large ($\alpha<0.8$) or the housing of the SSL product under test is large and brightly coloured. Throughout the self-absorption measurement of all SSL items under test, the auxiliary lamp must remain stable. For example, a consistent white LED source could be employed [6, 7].

The integrating sphere's size should be large enough to ensure that measurement errors caused by baffle and self-absorption by the test SSL product are minimal. Compact lights (size of ordinary incandescent and compact fluorescent lamps) normally have spheres of 1m or larger, whereas larger lamps have spheres of 1.5 m or greater (e.g., size of 4-foot linear fluorescent lamps and HID lamps). The sphere should also be large enough to prevent overheating from the light source being measured. Light sources of 500 W or more are normally measured with spheres of 2 m or larger [8].

It should be noted, however, that as the reflectance of the sphere increases, it becomes more susceptible to self-absorption effects and long-term drift, as well as having more spectral throughput variation. If the sphere has an opening, the average reflectance should be considered, and a greater coating reflectance will be beneficial to compensate for the fall in average reflectance. [9, 10].

To achieve appropriate spatial homogeneity of light integration and accurate correction in either geometry, the size of the SSL product under test should be limited for a given size of the sphere.

2. MATERIAL AND METHOD

2.1 Integrating Sphere-Based Method for Luminous Flux Measurement

The absolute luminous flux of each lamp is measured using an integrating sphere. Figure-1 shows the geometry of the NIS 2.5 m integrating sphere. It is consisting of a cosine corrected photometer equipped with *V(λ)* filter from the LMT company. The detector has a linearity response with a range of 16-28 nA/lx, based on these characteristics the total luminous flux can be

measured in direct substitution with the total luminous flux of standard lamps.

The sphere wall is coated with Barium Sulphatepaint with diffuse reflectance of approximately 97% in the visible region. The integrating sphere is also equipped with auxiliary lamp (100 W) tungsten on the sphere wall to measure the self-absorption effects of a lamp in the sphere. The room temperature of the photometry laboratory is controlled to be about 24°C. A temperature sensor is mounted to measure the air temperature of the space inside the sphere. During lamp operation, the ambient temperature in the sphere is approximately 25 °C. In our study, different groups of lamps under test to determine its luminous flux as well as its self-absorption factor; High-Pressure Sodium (HPS), High-Pressure Mercury (HPM), Metal Halide (MH), Double-Ended Halogen (DE), Compact (C1, C2, C3) and LED (W1, W2, W3) lamps.

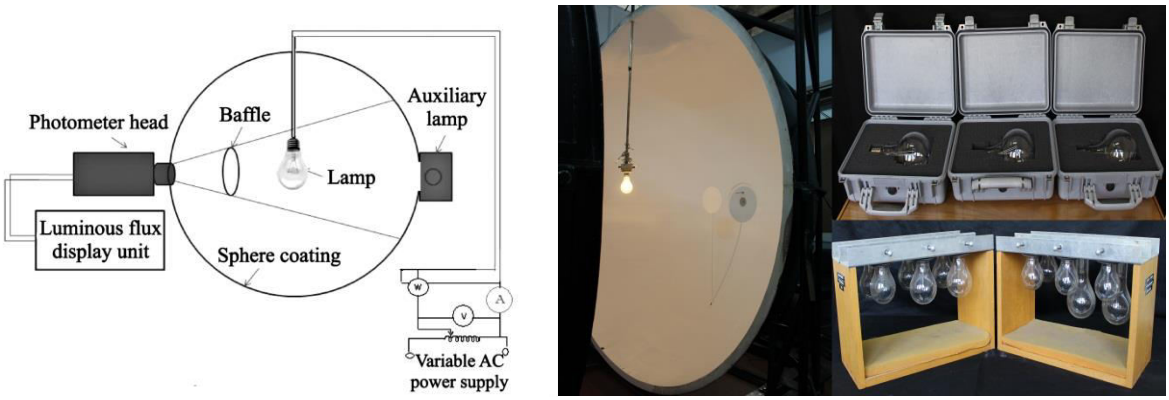

Figure-1. NIS 2.5 m integrating sphere set-up for luminous flux measurements.

3. RESULT AND DISCUSSIONS

3.1 Luminous Flux Measurements

The total luminous flux of the test lamp is obtained by comparison to that of a reference standard lamp according to Eq. (1):

$$\Phi_{TEST} = \Phi_{REF} . \frac{y_{TEST}}{y_{REF}} . \frac{F}{\alpha} \quad (1)$$

where Φ_{REF} is the total luminous flux (lumen) of the reference standard, $y_{TEST}$and y_{REF} are the photometer signals for SSL products under test and reference standard, respectively. F is the spectral mismatch correction factor, and α is the self-absorption factor. If factor F is not determined, F=1 should be used and the resulting uncertainty should be considered [2].

3.2 Self-Absorption Measurements

The self-absorption factor is given by Eq. (2):

$$\alpha(\lambda) = \frac{y_{aux,TEST}(\lambda)}{y_{aux,REF}(\lambda)} \quad (2)$$

where $y_{aux,TEST}(\lambda)$ and $y_{aux,REF}(\lambda)$ are the spectroradiometer readings for the auxiliary lamp when the SSL product under test or the reference total spectral radiant standard, respectively, are mounted in or on the sphere (4π or 2π geometry). In this case, the SSL product and the reference standard are not operated. Only the auxiliary lamp is operated [2]. Thus, the self-absorption factor $\alpha(\lambda)$ is always given concerning the null condition. Normally the same self-absorption factors can be used for the same type of lamp used with the same lamp holder in the same sphere. However, the values will change as the sphere coating or the lamp holder becomes contaminated. Self-absorption is more critical with higher reflectance sphere coatings. To determine the self-absorption correction, following steps are done:

- The standard lamp inside the sphere is switched off and the auxiliary lamp is lit. The reading of the photometer corresponding to the luminous flux of the auxiliary lamp and absorption for the presence of the standard lamp is measured.
- The standard lamp is replaced by the lamp under test which is not switched on. The auxiliary lamp remains lit and the reading of the photometer corresponding to the luminous flux of the auxiliary lamp and absorption of the lamp under test is measured and hence the self-absorption is calculated according to Eq. (2). The self-absorption factor has been measured for each lamp type accordingly the values of luminous flux are given and corrected inTable-1.

Table-1. Self-absorption factor effect on lamps group and its corrected luminous flux.

Lamp type		Measured Luminous flux (Lumen)	self-absorption factor α(λ)	Corrected luminous flux (Lumen)	Self-absorption effect (%)
High-Pressure Sodium (HPS)		16800	1.03	16310	2.90%
High-Pressure Mercury (HPM)		6300	0.99	6363	1.01%
Metal Halide (MHL)		9300	1.02	9117	1.96%
Double Ended Halogen (DE)		13770	1.08	12750	7.40%
Compact (C1)		2459	1	2459	0 %
Compact (C2)		5809	1.02	5695	1.96 %
Compact (C3)		4500	1.01	4455	1 %
LED (W1)		920	0.99	929	0.97%
LED (W2)		1230	0.99	1242	0.97%
LED (W3)		1475	1	1475	0 %

4. CONCLUSIONS

The absolute luminous flux in a lumen, as well as the self-absorption factor effect of different groups of lamps are studied. Due to the self-absorption factor, if test lamps are the same type as the standard lamps, the self-absorption does not or with minor effect such as in (LED) lamps groups results. Self-absorption correction is critical since the physical size and shape of SSL products and lamps under test are typically very different from the reference lamp size and shape, consequently, the luminous flux should be corrected. Results show that the worst-case error and higher self-absorption are found either in Double-ended halogen (DE) lamp up to 7, 4 % or in High-Pressure Sodium (HPS) lamps up to 2.9 %. In High-Pressure Mercury (HPM), Metal Halide (MH), Compact (C1, C2, C3) and LED (W1, W2, W3) self-absorption is changing from 0% to 1.96%. Hence, Industry standards recommend applying absorption correction techniques for situations where the physical configuration and characteristics of the lamp or LED under test differ from the reference lamp.

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