Uncertainty Estimation of Spectral Mismatch Correction Factor for Incandescent Lamps

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KEYWORDS	A B S T R A C T
Spectral Mismatch correction Factor, Lamp Seasoning, Uncertainty, Total luminous flux, Commercial Incandescent Lamp, Integrating Sphere Photometer	In the present research, uncertainty of spectral mismatch correction factor of total luminous flux measurements are estimated for some types of commercial incandescent lamps. A set of eight incandescent lamps have been seasoned for 60 hours and the aging curves have been drawn for each lamp. A set up based on NIS Spectroradiometer ocean optics HR 2000 with uncertainty 4.7% and the photometric bench has been used for measuring the spectral power distribution of the lamps to determine the spectral mismatch correction factor and estimate the uncertainty due to this factor. Another set up based on 2.5meter NIS integrating sphere and NIS photometer LMT U1000 with uncertainty 4% and a group of NIS luminous flux standard lamps calibrated at National Physical Laboratory in England (NPL) with uncertainty 0.8% are used to measure the total luminous flux for the eight incandescent lamps during the lamp seasoning. This research demonstrates and realizes the process required to determine the spectral mismatch correction factor and to estimate the uncertainty due to it for some commercial lamps to improve their total luminous flux measurements. The spectral mismatch correction factors are varied from approximately 0.13% when using the 2400 K standard lamps to approximately 0.14% when using the 2750 K standard lamps. Also, the uncertainty estimation for spectral mismatch correction factors are varied from 0.00062 to 0.00847 depending on the correlated color temperature of the standard lamps.

Introduction

The incandescent lamp is the oldest of the major electric light source families. The viability of this source over the years is a consequence of its many advantages and relatively few disadvantages. Simplicity, low cost construction, and excellent color rendition are major attributes of this class of light source [1].The incandescent lamp is a lamp that creates radiant energy when its metallic filament is heated by an electric current. The filament is designed to produce radiant energy in the visible portion of the

electromagnetic spectrum (light). The filament is of a special material that is supported in an envelope (bulb) that has been evacuated or filled with an inert gas such as argon, nitrogen, or krypton. In addition to light, the heated filament emits infrared and ultraviolet energy. When either of these radiations is accentuated, the lamp may be used as a source of that energy.

The important parts of an incandescent lamp are the bulb (envelope), the filament, and the base. The bulb may be clear, colored, inside-frosted, or coated with diffusing or reflecting material. Most lamps have soft-glass bulbs; hard glass is used when the lamp will be subjected to sudden and severe temperature changes. Lamps have a variety of bulb shapes, base types, and filament structures.

Luminous flux lamps should be handled carefully to avoid mechanical shocks to the filament. They are normally operated in the base-up position and seasoning should be conducted in the same burning position. The lamp must always be operated in the same burning position. Before luminous flux working standards lamps are submitted for calibration, they must be seasoned and tested for stability. These incandescent lamps are usually operated on DC power in order to have much better stability of power supplies, better accuracy of electrical measurements than on AC power and to avoid problems of flicker under AC operation. During the seasoning process, the tungsten filament of the lamp is partially recrystallized according to the electrical polarity applied. If the polarity is changed, the lamp filament may undergo a change of state. Therefore, the polarity should be kept the same when the lamps are seasoned and when they are used. The polarity should be marked on the lamp base or it should be clearly defined in a document [2].

The lamps intended to be used for measuring photometric, colorimetric, and electrical characteristics should be seasoned [3] until any time-related change in these characteristics becomes small. For new lamps of almost every type, the greatest rates of change in the operating characteristics generally occur during the first hours of operation.

Normal seasoning is generally performed at rated voltage for a minimum period of one-half of 1 percent of rated life. Lamps should be seasoned in the "base-up" position. The position used during seasoning must be maintained throughout subsequent testing and it must be noted in the test report.

Accelerated seasoning is not recommended for tungsten halogen lamps, and is not recommended for lamps having a rated life of 100 hours or less. The following two equations [4,5] allows the direct calculation of accelerated seasoning minutes (ASM):

$$ASM = 60 \left[\frac{(0.005 \times Rated\ Life)}{(Percent\ Volts)^{13}} \right] \quad (1)$$

$$ASM = 60 \left[\frac{(0.005 \times Rated\ Life)}{(Percent\ Amp)^{24}} \right] \quad (2)$$

where :

The numerator $(0.005 \times Rated\ life)$ is the minimum normal seasoning hours for the lamp that is to undergo accelerated seasoning. Percent volt and percent ampere are expressed as the decimal, voltage or current ratio. For example, if a voltage rated lamp is operating at 120 percent of rated volts, the dominator in Equation (1) should be evaluated as Equation (2) [5].

In photometry, the comparison device is the photometer. Since no photometer perfectly

matches the $V(\lambda)$ curve, we need to determine how closely we approach the $V(\lambda)$ curve. The output of a photometer is a single number; the integration over the spectral range is all done internally and one number comes out.

Most photometers are calibrated using what is called the CIE Illuminant A, which is spectrally "smooth" light source, similar to a blackbody radiator operating at 2856K [6].

When the photometers measure light sources whose spectral distribution is different from the CIE Illuminant A, an error occurs due to the spectral mismatch of the photometers. This error is corrected by a spectral mismatch correction factor [7].

An error occurs when a photometer measures a light source having a spectral power distribution different from the standard source for which the photometer was calibrated. In order to correct for such spectral mismatch error, the photometer must be characterized for its relative spectral responsivity. The spectral mismatch correction factor SCF is given by [8].

$$SCF = \frac{\int_{360}^{830nm} P_e^T(\lambda) \times V(\lambda)\,d\lambda \int_{all-wavelength} P_e^S(\lambda) \times R(\lambda)\,d\lambda}{\int_{all-wavelength} P_e^T(\lambda) \times R(\lambda)\,d\lambda \int_{360}^{830nm} P_e^S(\lambda) \times V(\lambda)\,d\lambda} \quad (3)$$

where

$P_e^T(\lambda)$: is the relative spectral output of the test source.
$P_e^S(\lambda)$: is the relative spectral output of the standard source.
$R(\lambda)$: is the relative spectral responsivity of the photometer.

$V(\lambda)$: is the spectral luminous efficiency function, which defines a photometric measurement.

Uncertainty of the determination of the spectral mismatch correction factor u(SCF) which can be determined regarding to Equation (3) and according to reference [9, 10] by the following equation:

$$u^2 = \sum_{var_{iable}} \left(\frac{\partial SCF}{\partial \, var\,iable}\right) \times u^2(var\,iable) \quad (4)$$

Hence we have

$$u^2(SCF) = \delta^2 P_{iS}\left(\frac{\partial SCF}{\partial P_{iS}}\right)^2 + \delta^2 P_{it}\left(\frac{\partial SCF}{\partial P_{it}}\right)^2 + \delta^2 R_i\left(\frac{\partial SCF}{\partial R_i}\right)^2 \quad (5)$$

Where

P_{iS} : the summation of $P_e^S(\lambda)$ within the visible wavelengths range.
P_{it}: the summation of $P_e^T(\lambda)$ within the visible wavelengths range.
R_i: the summation of $R(\lambda)$ within the visible wavelengths range.

Then from equation (2) we have

$$u(SCF) = \sqrt{\delta^2 P_{iS}\left(\frac{\partial SCF}{\partial P_{iS}}\right)^2 + \delta^2 P_{it}\left(\frac{\partial SCF}{\partial P_{it}}\right)^2 + \delta^2 R_i\left(\frac{\partial SCF}{\partial R_i}\right)^2} \quad (6)$$

Methods and experimental set-up

Aging lamps

All the total luminous flux lamps are clear round bulb. All lamps are from NIAZA Company in Egypt, they are three groups of different watts. The eight lamps were each set to operate at a correlated color

temperature (CCT) for each lamp as shown in Table (1). The lamps seasoned or aged for approximately 60 hours to be sure from the photometric characterization stability for each lamp. The lamps were aged by using the NIS setup of aging lamps as shown in Figure (1). The data was measured every ten hours.

Measurement Set-up of the total luminous flux quantity during seasoning the lamps

The NIS photometer used is LMT U1000 and the integrating sphere [11] used has a diameter of 2.5 meter and is coated internally with a uniform layer of barium sulfate ($_{BaSO_4}$).The spectral quality factor $f_1^{'}$ for the photometer has been determined for the sphere-photometer with value 6.25% [12]. The flux lamps are mounted in a base-up configuration at the center of this sphere into a lamp socket supported from the top of the sphere. Figure 1, shows the 2.5 meter diameter integrating sphere

Measurement Set up of the spectral power distribution of the lamps

The Set up of measuring the spectral power distribution lamps is in Figure. 3. It measured directly using the photometric bench and the Spectroradiometer ocean optics HR 2000 at NIS with uncertainty 4.7% [13,14].

Results and Discussion

The results of the lamp aging are presented in Figures (4) to (11). The equation of the fitted line in Figures (4) to Figure (11) represent the aging rate of lamps. The equation in each figure contains two values Φ and t, where Φ is the normalized photometer reading and t is the aging time for this reading. Φ is a function of the slope (the rate of changing of lamp output per unit

time) and the Φ intercept (Φ value at t=0).These curves are very useful to determine the uncertainty due to the aging of the lamps when we use them as working standard lamps. The electrical control parameters of the OSRAM Luminous Flux Standard Lamps and NIAZA lamps for the measurements performed are given in the Table 1 and Table 2.

Uncertainty

Modern metrology practice in any field requires accurate estimation of uncertainties. The concept of uncertainty as a quantifiable attribute is relatively new in the history of measurement, although error and error analysis have long been a part of the practice of measurement science or metrology. It is now widely recognized that, when all of the known or suspected components of error have been evaluated and the appropriate corrections have been applied, there still remains an uncertainty about the corrections of the stated result, that is, a doubt about how well the result of the measurement represents the value of the quantity being measured.

Consistent estimation of uncertainty according to the methods described in the ISO Guide to the Expression of uncertainty in Measurements [15] is a major concern of modern metrology. This applies not only to the direct measurement of International System of Units quantities, but also to measurements derived from them.

All uncertainties are given as fractional uncertainties and as one standard deviation (coverage factor k=1). The relative expanded uncertainty (k=2) was obtained by assuring a normal distribution and multiplying the relative combined standard uncertainty by a coverage factor of k=2.

Table.1 The electrical control results of NIS standard lamps

NIS Standard Lamps	SET Current (amperes)	Voltage (Volts)	Color temperature (Kelvin)	Total luminous flux (lumen)
NIS-E21	1.7869	102.1	2750	2587
NIS-E22	1.7991	101.6	2750	2597
NIS-E31	0.20482	91.9	2400	131.5
NIS-E32	0.20315	92.0	2400	130.8
NIS-E33	0.20382	92.4	2400	132.4

Table.2 the electrical control results of commercial incandescent lamps

NIS Standard Lamps	SET Current (amperes)	Voltage (Volts)	Color temperature (Kelvin)	Total luminous flux (lumen)
NIS-1-200	0.6050	116.7	2095	232
NIS-2-200	0.6052	113.7	2070	225
NIS-3-200	0.6051	117.0	2073	244
NIS-1-150	0.4551	114.9	2074	150
NIS-2-150	0.4551	116.7	2054	164
NIS-3-150	0.4551	114.5	2084	152
NIS-1-100	0.3050	116.9	2049	89
NIS-2-100	0.3050	116.8	2043	89

Table.3 Spectral Mismatch Correction Factors (SCF) for standard lamps

| Lamp	Spectral Mismatch Corrections
NIS-E21	0.979180
NIS-E22	0.980783
NIS-E24	0.980738
NIS-E31	0.977065
NIS-E32	0.979680
NIS-E33	0.974953

Table.4 Spectral Mismatch Correction Factors (SCF) for Test Lamps.

Lamp	Spectral Mismatch Correction
NIS-1-200	0.980564
NIS-2-200	0.980753
NIS-3-200	0.980508
NIS-1-150	0.979971
NIS-2-150	0.979849
NIS-3-150	0.980508
NIS-1-100	0.979724
NIS-2-100	0.979494

Table.5 The uncertainty values of the total luminous flux due to the spectral mismatch correction factor

Lamp	NIS-E21	NIS-E22	NIS-E24	NIS-E31	NIS-E32	NIS-E33
NIS-1-200	0.0006247624	0.0014064372	0.0013177160	0.0084815468	0.0084546494	0.0084771962
NIS-2-200	0.0006276957	0.0014060538	0.0013176408	0.0084822906	0.0084553585	0.0084779460
NIS-3-200	0.0006239332	0.0014080705	0.0013192043	0.0084827849	0.0084559155	0.0084784427
NIS-1-150	0.0006204833	0.0014082405	0.0013193767	0.0084777323	0.0084509426	0.0084733446
NIS-2-150	0.0006204201	0.0014061166	0.0013171816	0.0084737744	0.0084470187	0.0084693990
NIS-3-150	0.0006208521	0.0014052314	0.0013161234	0.0084756993	0.0084488980	0.0084713251
NIS-1-100	0.0006223320	0.0014021372	0.0013131910	0.0084671352	0.0084403928	0.0084627440
NIS-2-100	0.0006216664	0.0014121198	0.0013231320	0.0084757388	0.0084490317	0.0084713366

Figure.1 The NIS Aging system for Lamps photometer at NIS, Egypt
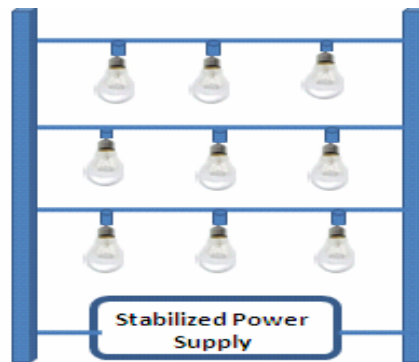
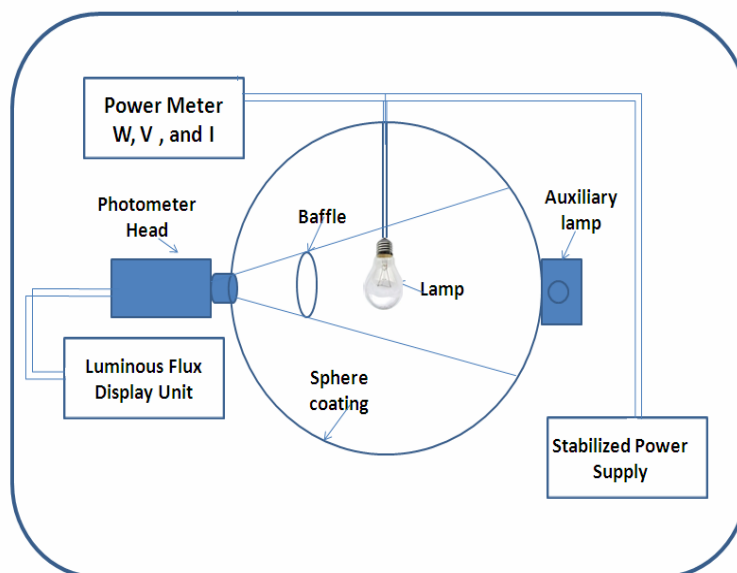**Figure.2** The NIS integrating sphere photometer system set up for the luminous flux measurement

Figure.3 Set up of measuring the spectral power distribution of NIS total luminous flux working standard lamps
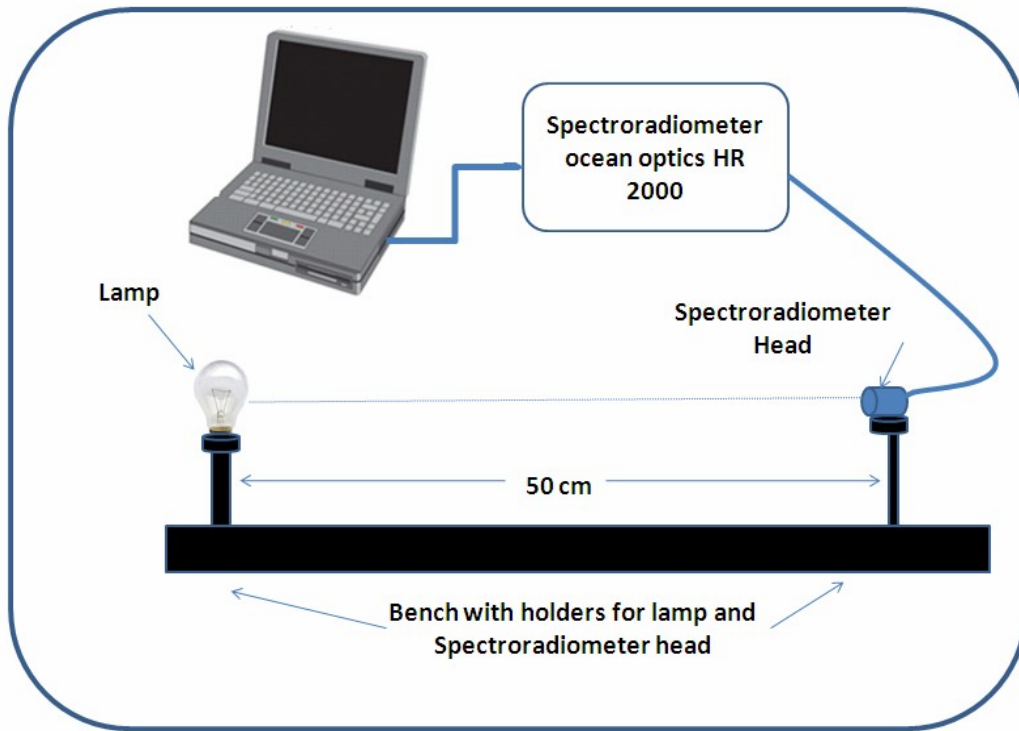

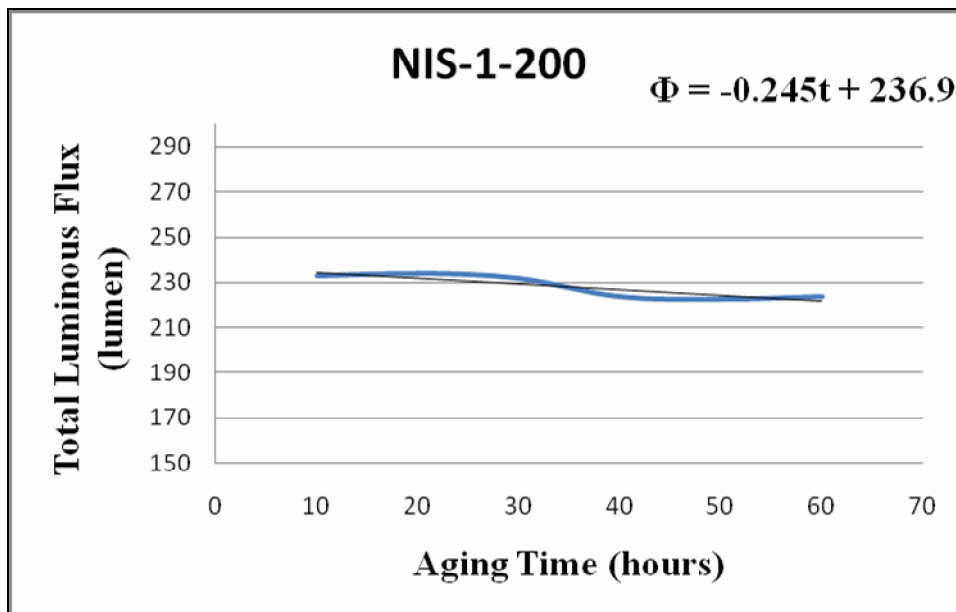**Figure.4** The aging curve of NIS-1-200
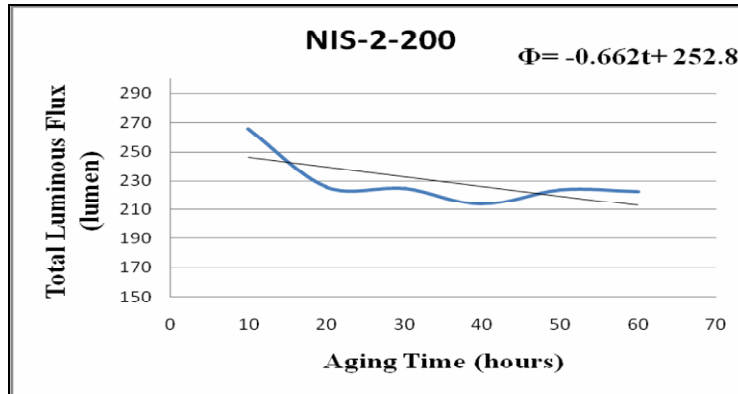
Figure.5 The Aging Curve of NIS-2-200

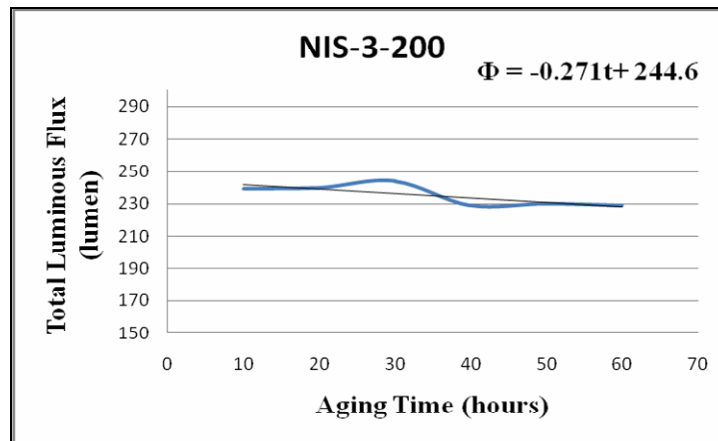**Figure.6** The aging curve of NIS-3-200

Figure.7 The aging curve of NIS-1-150
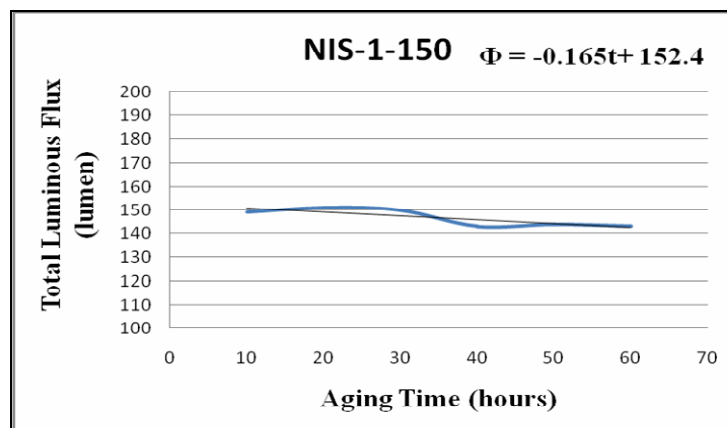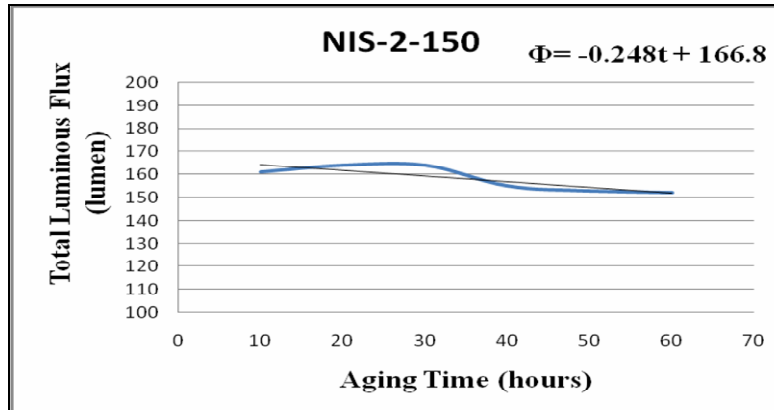
Figure.8 The aging curve of NIS-2-150

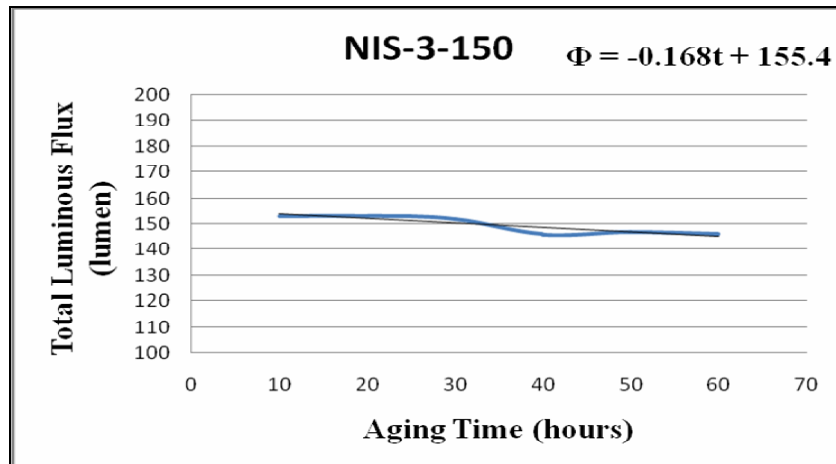**Figure.9** The aging curve of NIS-3-150

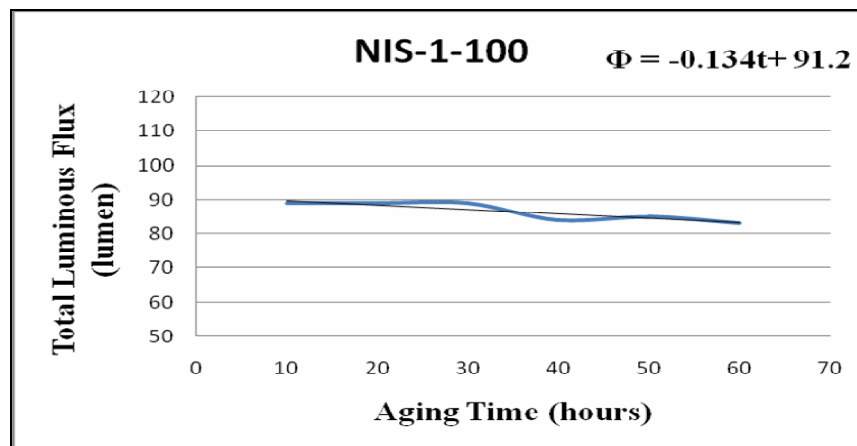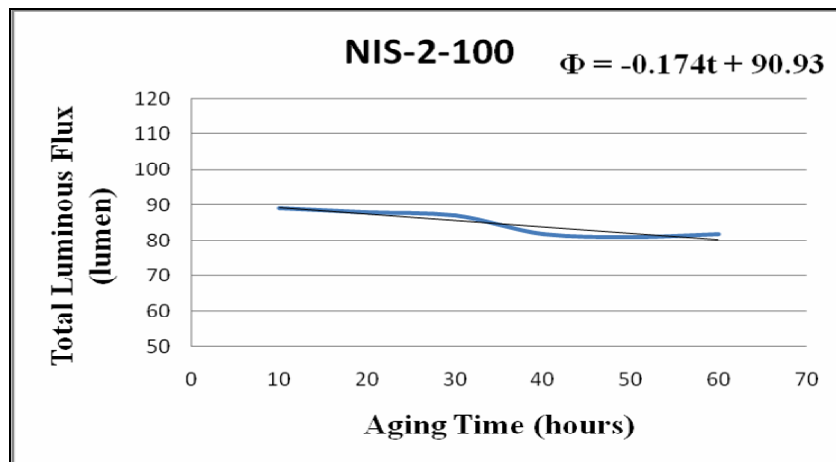**Figure.10** The aging curve of NIS-1-100

Figure.11 The aging curve of NIS-2-100

NIS photometer LMT U1000 with uncertainty 4%, NIS Spectroradiometer with uncertainty 4.7% and NIS-standard lamps calibrated at National Physical Laboratory in England (NPL) with uncertainty 0.8%. Uncertainty of sphere calibration photometer factor (0.15%) and Photometer Spectral Quality Factor $f_1^{'}$ equal 6.25% [12]. The spectral mismatch correction factors are varied from approximately 0.13% when using the 2400 K standard lamps to approximately 0.14% when using the 2750 K standard lamps. Also, the uncertainty estimation for spectral mismatch correction factors are varied from 0.00062 to 0.00847 depending on the correlated color temperature of the standard lamps as shown in Table 4 and Table 5.

Conclusions

The aging curves presented in Figures (4) to (11) are very useful to determine the uncertainty due to the aging of the lamps when it used as working standard lamps.
The aging of the lamps to determine whether they were adequately stable for use as standard lamps. It was found that the typical aging time of 48 hours was sufficient for the incandescent lamps used, and that by recording the change in lamp output with time we could determine that the lamps had stabilized to a uniform aging rate, and that we could use this data to estimate an uncertainty in the calibration of the lamp due to the aging of the lamps.

The aging data could also be used to determine when the lamp should be re-calibrated in order to maintain a desired accuracy for the total luminous flux output of the lamp.

The spectral mismatch correction factors are varied from approximately **0.13%** when using the 2400 K standard lamps to approximately **0.14%** when using the 2750 K standard lamps.

The uncertainty estimation for spectral mismatch correction factors are varied from 0.00062 to 0.00847 depending on the correlated color temperature of the standard lamps.

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