Size-of-source (SSE) effect of broadband and interference filters for Double Wavelength Thermometers

S Yurtseven¹, O Pehlivan² and H Nasibov³

¹ Researcher, TUBITAK UME, Kocaeli, Turkey
² Chief Senior Researcher, TUBITAK UME, Kocaeli, Turkey
³ Chief Senior Researcher, TUBITAK UME, Kocaeli, Turkey

E-mail: humbet.nasibli@tubitak.gov.tr

Abstract. In this work we present a comparative study of an impact of several optical windows (the SCHOTT glass filters (KG1 to KG5) with a broadband transmittance in the visible spectral range) and an interference filter (with a peak transmittance at 650 nm) on the size-of-source effect (SSE) of a radiation thermometer. The investigations were performed in the scope of the development of a Double Wavelength Radiation (DWT) thermometer at UME. There are two radiometric channels in the DWT, where one of the channels will comprise of a broadband transmittance filter, while the other - an interference filter. In order to exclude the optical path effects on the SSE measurements the investigations were performed on a single channel radiation thermometer. The SSE measurements were performed by means of the indirect method. The SSE measurement results are illustrated and discussed.

1. Introduction

In 2018 the kelvin will be redefined in terms of a fixed value of the Boltzmann constant (k) (i.e. in terms of fundamental constant nature) [1]. In order to fulfill this transition (from the triple point of water to the Boltzmann constant (k)) in the definition of the kelvin the international temperature metrology community performed extensive work as in the precise determination of the Boltzmann constant (k) value as well as in working out of the mise en pratique (MeP-K). The MeP-K is a practical documentary guide aimed to help practitioners of the thermometry (mainly NMIs) in the realization of the 'new' kelvin [1,2]. Among primary methods involved to determine the Boltzmann constant (k), important advancements have been obtained over the past decade on Acoustic gas thermometry, Dielectric constant gas thermometry, Johnson noise thermometry and Doppler-broadening thermometry [1,3]. Most of these activities are being performed in the frame of two projects “Implementing the new kelvin” namely INK1 [4] and INK2 [5]. Currently TUBITAK UME, in the frame of the EMPIR INK2 project [5], is developing a new double-wavelength radiation thermometer (DWT) specifically for the radiometric temperature measurements traceable to synchrotron radiation. On contrary to the presently used absolute radiometric methods (where the traceability to the watt via a cryogenic radiometer is required), the DWT method allows the measuring of the thermodynamic temperature only from the relative radiance measurements [6-8].

One of the most important instrumental factors affecting the performance of any radiation thermometer (including the DWT under the construction) is the size-of-source effect (SSE) [9-10]. In general, any radiation thermometer has a nominal target size at its working distance, and this target size (generally, specified in the design stage) is defined by the field of view of thermometers optics. Ideally, only all radiant flux emanating from the target spot within the...
field of view should reach a detector surface. However, in practice, the radiant flux at the
detector surface contains a radiation from outside the target spot of the thermometer. Besides,
some radiation from inside the field of view can be lost due to diffraction and scattering effects.
The dependence of the radiant flux at the detector surface on the size of the source is known as a
SSE, that impacts on both the calibration and use of radiation thermometers. Among the other
factors affecting the SSE a surface and bulk scattering of optical components plays important
role. The DWT under construction comprises of two radiometric channels, where one of the
channels will has a broadband transmittance filter, while the other - an interference filter. In this
work we measured and compared SSE of four Schott glasses KG1, KG2, KG3 and KG5 and one
interference filter.

2. Experimental setup

There is not a common method to assess the SSE of radiation thermometers. Among the variety
of methods for measuring of the SSE in frame of thermometry two methods named as “direct
method” and “indirect method” are widely used [9]. In both methods the SSE is measured by
means of a large aperture variable-diameter uniform radiance source where in spite of the first
method in the second method measurements are performed by using of a central target [9].
Here we performed SSE measurements by employing the indirect method. A black spot of 3 mm
in diameter (fixed on a glass window by such a way that the center of the black spot and center
of output port of the sphere coincides) was used as a target. In order to exclude the optical path
effects on the SSE measurements the investigations were performed on a same single channel
radiation thermometer. For this purpose we use a transfer radiation thermometer TSP-2
(VEGA). Fig.1 shows the TSP-2 and the SSE measurement setup. A schematic of optical layout
of the TSP-2 is shown in Fig 2.

The SSE measurements of all filters were performed on the same setup (Fig.1.) [11], where an
integrating sphere (with a diameter of 400 mm) was used in experiments. The sphere comprises
of one output port with a diameter of 60 mm. Four incandescent lamps connected in series and
 corresponding four internal baffles (placed at specific locations by such a way that to minimize
the specular reflection at the output port) are located inside the sphere. Apertures (made from
anodized aluminum) with an internal diameter of 5, 8, 10, 15, 20, 30, 40 and 50 mm were used to imitate a variable–diameter source. In order to exclude the influence of black spot supporting glass window's transmittance in the SSE measurements, another identical glass window without the spot (a blank glass window) was used in combination with the apertures. The transmittance of the spot at the working wavelength band of the thermometers was assessed to be smaller than 0.01%. The lamps are supplied by a controlled DC current, and are switched on at least one hour before the measurements for establishing the quasi-isothermal condition. The measurements were performed at 600 mm from the outer surface of the black spot.

3. Results and discussions

The TSP-2 has a plug in measurement head that comprises only of a filter and a detector assembly (the inset in Fig 1). So, in experiments it was very easy to change the filter under the test and perform the measurements. All glass filters namely KG1, KG2, KG3 and KG5 used in the measurements are uncoated. The SSE was calculated using the following equation:

\[
SSE = \frac{(S_{\text{spot}} - S_{\text{dark}})}{(S_{\text{aperture}} - S_{\text{dark}})},
\]

where \(S_{\text{spot}}\) is the signal measured when the thermometer is focused on the black spot, \(S_{\text{aperture}}\) is the signal measured when the aperture is combined with the blank glass window, and \(S_{\text{dark}}\) is the relevant dark signal. This measurement is repeated with all apertures of varying internal diameters. First, we measured the SSE of the TSP-2 without any filters, where the results of two measurements performed by two operators at different days are illustrated in Fig 3. and Table 1. The average value of two independent SSE measurement results for all filters under the test are summarized in Table 1. Similarly, Fig.4. depicts the plots of the SSE measurements of all filters in the current experiments.

As it's expected the SSE value is increased for the configurations with the filters. Such as increase of the SSE values with the filters are originated mainly due to the inter-reflections and surface and bulk scatterings. However, there is no significant scattering in the SSE values of five filters at the same aperture diameter. The maximum standard deviation is about 0.038 at aperture diameter of 8 mm, and the average value of the standard deviation is about 0.029 for all apertures. These results demonstrated that for a radiation thermometer that is optimized for the SSE effect by properly installing of a Lyot stop, as it was shown in [10], the contribution of the broadband and interference filters to the total SSE
effect will be comparable. One of these KG glass filters and the interference filter will be used in the construction of the DWT and the results will be published in detail elsewhere.

Table 1. The obtained SSE (%) results.

| Aperture (mm) | Without Filters | With filters | Difference | Interference filter (650 nm) |
|--------------|-----------------|--------------|------------|----------------------------|
|              | 1st round | 2nd round | Difference | KG1 | KG2 | KG3 | KG5 |
| 5            | 0.307     | 0.308     | 0.002      | 0.319 | 0.357 | 0.341 | 0.388 | 0.372 |
| 8            | 0.379     | 0.381     | 0.002      | 0.369 | 0.443 | 0.425 | 0.459 | 0.465 |
| 10           | 0.417     | 0.419     | 0.002      | 0.473 | 0.547 | 0.488 | 0.532 | 0.532 |
| 15           | 0.507     | 0.510     | 0.003      | 0.609 | 0.662 | 0.608 | 0.655 | 0.644 |
| 20           | 0.580     | 0.580     | 0.000      | 0.680 | 0.740 | 0.681 | 0.738 | 0.737 |
| 30           | 0.684     | 0.685     | 0.001      | 0.788 | 0.802 | 0.780 | 0.829 | 0.788 |
| 40           | 0.757     | 0.758     | 0.001      | 0.836 | 0.864 | 0.830 | 0.899 | 0.890 |
| 50           | 0.815     | 0.816     | 0.001      | 0.853 | 0.895 | 0.885 | 0.938 | 0.930 |

4. Conclusion

The use of the SCHOTT broadband glasses KG1 to KG5 series as a band filter in radiation thermometry is new, and therefore, precise and comparative characterisation of the behaviour of these filters inside a radiation thermometer has a certain interest in the field, especially in the design of DWT. In this work a series of 4 mm thickness glass filters (KG1, KG2, KG3 and KG5) are subjected to the SSE tests and compared with the results of an interference filter conventionally widely used in radiation thermometry. These preliminary investigations demonstrated that the difference between SSE contributions of the examined glass filters and the interference filter is negligible small and both filters can be used in DWT thermometers.

Acknowledgments

This work was funded by the EMPIR project 'Implementing the new kelvin 2', coordinated by Graham Machin. The EMPIR is jointly funded by the EMPIR participating countries within EURAMET and the European Union.

References

[1] Machin G 2018 Meas. Sci. Technol. 29 022001
[2] Fellmuth B et al 2018 Phil. Tran. R. Soc. A 374 20150037
[3] Gotti R et al 2018 Phys. Rev. A 97 012512
[4] Machin G et al 2016 Phil. Tran. R. Soc. A 374 20150053
[5] The InK 2 website is at www.vtt.fi/sites/ink2
[6] Prokhorov A et all 2015 Int. J. Thermopys 36 252-266
[7] Woolliams E R et all 2009 Int. J. Thermopys 30 144-154
[8] Saunders P 2014 Int. J. Thermopys 35 417-437
[9] Machin G, Sergienko R 2001 Proc. TEMPMEKO The 8th International Symposium on Temperature and Thermal Measurements in Industry and Science Vol 8 (Berlin, Germany) p 155
[10] Yoon H.W, Allen D W, Saunders R D 2005 Metrologia 42 89-96
[11] Nasibov H et all 2015 Int. J. Thermopys 38 112