STANDARD BLACKBODY FOR INFRARED TYMPANIC THERMOMETERS

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Abstract: Infrared tympanic (ear) thermometers have been in widespread use for clinical care for these years and consequently their accuracy and repeatability shall be our main concern. A standard blackbody source traceable to the International Temperature Scale of 1990 (ITS-1990) has been developed in Center for Measurement Standards (CMS), Taiwan, for the evaluation and calibration of infrared ear thermometers over the range from 35 °C to 42 °C. The estimated uncertainties of the standard blackbody with coverage factor k=2 are 31 mK at 38 °C and 36 mK at 42 °C.

1. INTRODUCTION

Temperature measurement is a key aspect in the diagnosis of disease and is important in the monitoring of patient health. For instance, electrical clinical thermometers or infrared ear thermometers were used extensively to screen patients against the Severe Acute Respiratory Syndrome (SARS) in 2003 according to World Health Organization (WHO) that this illness generally begins with a prodrome of fever (>38°C)[1].

Infrared ear thermometers have the advantage of being relatively easy to use and have a quick response; so have been widely used for clinical care. They measure the infrared radiation from the tympanic membrane, which shares the same blood supply as the hypothalamus, and the ear canal. However, reading variations prevalently exists among various commercial IR ear thermometers according to our tests, that is, it manifest that the accuracy should be the most significant issue in view of medical diagnosis. It is therefore imperative that IR tympanic thermometer be regularly calibrated and traceable to ITS-90. To address this need, CMS set up a standard blackbody for both evaluation and calibration of IR tympanic thermometers.

2. STANDARD BLACKBODY FOR IR TYMPANIC THERMOMETERS

The standard blackbody consists of a blackbody cavity vertically immersed in a temperature controlled stirred water bath. The design principles of a high-quality blackbody cavity are that the area of the opening aperture is sufficiently small in comparison with the total internal surface area of the cavity, the small-diameter aperture, and being fabricated of high thermal conductivity metal. Therefore, a blackbody with high and uniform emissivity and even approximately isothermal cavity will be obtained.

The blackbody cavity as shown in figure 1 is designed with conical configuration referring to that suggested by the ASTM E-1965-98 standard[2] and is constructed using oxygen-free copper with high thermal conductivity. The interior surface of the copper cavity is coated with high emissivity black paint (Flame Proof EP-10, ε =0.95). The cavity is connected to a surface box fabricated of ABS (Acrylonitrile Butadiene Styrene) plastic having low thermal conductivity.

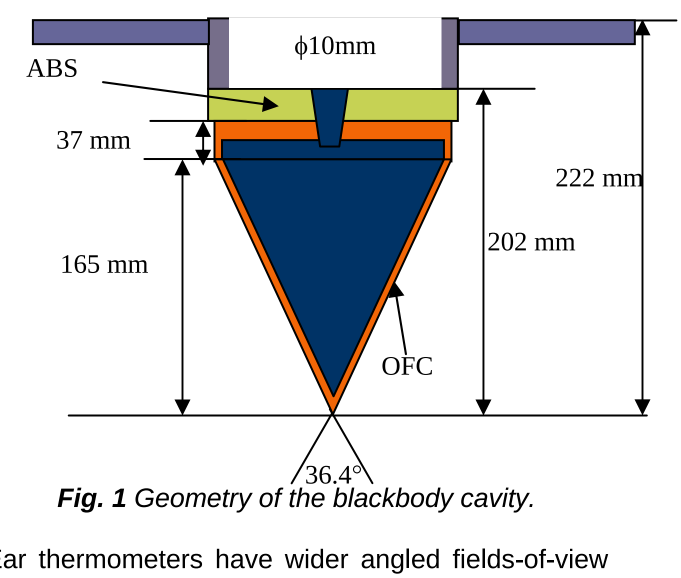

***Fig. 1** Geometry of the blackbody cavity.*

Ear thermometers have wider angled fields-of-view compared to most conventional radiation thermometers, therefore small aperture of 10 mm diameter of the cavity is helpful to reduce the measurement errors.

2.1. Effective emissivity evaluation

The effective emissivity of blackbody cavity is evaluated by using Monte Carlo method[3]. The calculations of effective emissivity of an opaque surface are based on reciprocity theorem and the technique of inverse ray tracing. By choosing reference temperature T_{ref} and a large number of rays, n, the total effective emissivity of the cavity can be expressed by

$$\varepsilon_{eff}(\lambda,T_{ref}) = \frac{\exp\left(\dfrac{C_2}{\lambda T_{ref}}\right)-1}{n}\sum_{i=1}^{n}\sum_{j=1}^{m_i}\frac{\varepsilon_j(\lambda)}{\exp\left(\dfrac{C_2}{\lambda T_j}\right)-1} \times \prod_{k=1}^{j-1}\rho_k(\lambda) \quad (1)$$

m_i : the number of ray reflection in the i-th trajectory
λ : the wavelength
C_2: the second radiation constant in Plank's law
$\varepsilon_j, \rho_j, T_j$: the emissivity, reflectance and temperature in the j-th of reflection

The initial conditions of the effective emissivity are (a) the emissivity of the black coating surface is 0.95, (b) the ratio of the aperture area to the total internal surface area of the cavity, (c) average normal view, and (d) the number of rays for ray tracing is 1×10^4. The number of rays we choose is the maximum value the software can supply, assuming the perfect cavity being capable of numerous reflections.

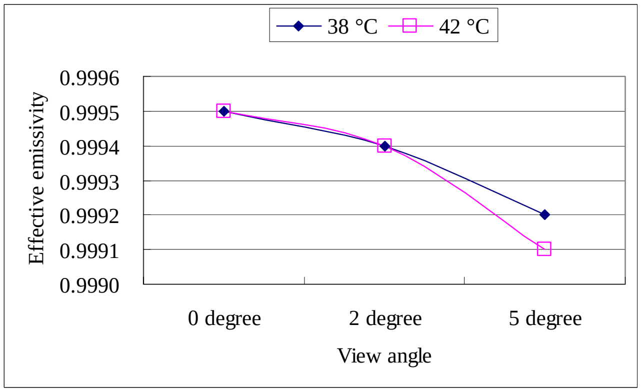

Fig. 2 *The effective emissivity vs. view angles at 38 ℃ and 42 ℃*

The view angle is within 5 degrees according to our design of cavity. The effective emissivity versus view angles less than 5 degrees under Monte Carlo calculations at 38 °C and 42 °C are shown in figure 2. It reveals there is no significant difference in effective emissivity between 38°C and 42 °C with view angles less than 2° and nearly approach to 1.

2.2. Evaluation of the water bath

The temperature uniformity of the temperature controlled stirred water bath are assessed by measuring the temperature difference by two calibrated PRTs, with a diameter of 3 mm, which contacts tiltedly beside the cavity; immersed in the 40 l water bath; at two positions. One of which is placed at the tip of the cavity while the other is also placed at the outer surface of the cavity but at a vertical distance of 121 mm from the tip.

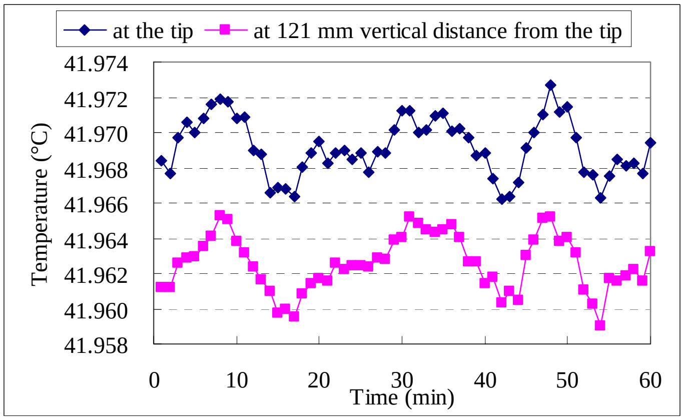

Fig. 3 *The temperature uniformity and stability of the standard blackbody at 38 ℃*

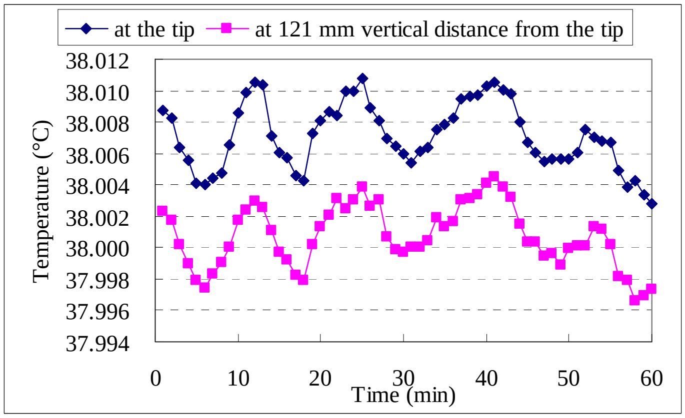

Fig. 4 *The temperature uniformity and stability of the standard blackbody at 42 °C*

The temperature stability of the water bath can just be estimated by the PRT placed at the tip over the period of 1 hour.

The results shown in figures 3 and 4 represent that the bath is uniform to within 7.8 mK and is stable to within 8.0 mK whatever the bath temperature is 38 °C or 42 °C. That is, the bath performance meets the requirements of standards like ASTM E1965-9, EN 12470-5:2003[4], and JIS T4207: 2005[5].

3. UNCERTAINTY BUDGET OF STANDARD BLACKBODY

The uncertainty budget of the radiance temperature is shown in Table 1. The uncertainty source of reference temperature mainly originates from the PRT and consists of PRT standard traceability uncertainty, PRT reproducibility, resistance bridge resolution, and resistance bridge drift uncertainty. The uncertainty source resulted from view angle within 5 ° is estimated via the temperature variation corresponding to the emissivity change within five degrees view angle. Under the ambient temperature of 21°C to 25, the uncertainty caused by cavity emissivity is estimated to be 8.5 mK at 38 °C and 12.5 mK at 42 °C.

Table1: Uncertainty budgets for the standard blackbody at 38 °C and 42 °C

Uncertainty Sources	38 °C Bath Temperature	42 °C Bath Temperature
Reference temperature	8 mK	8 mK
Cavity heat loss at (23.0±2) °C	<1 mK	2 mK
Cavity emissivity at (23.0±2) °C	8.5 mK	12.5 mK
View angle within 5 °	10 mK	10 mK
Ray tracing	<0.001 mK	<0.001 mK
Combined uncertainty	15.4 mK	18.0 mK
Expanded uncertainty (k=2)	30.8 mK	36.0 mK

4. CONCLUSIONS

CMS has developed a standard blackbody source consisting of a blackbody cavity vertically immersed in a temperature controlled stirred water bath for the evaluation and calibration of infrared tympanic thermometers over the range from 35 °C to 42 °C.

Both the stability and uniformity of the water bath are less than 8 mK and meets the requirements of standards such as ASTM E1965-9, EN 12470-5:2003, and JIS T4207: 2005, i.e. stability within ±20 mK and uniformity within ±10 mK. The effective emissivity of the cavity is estimated to near 1 within 5 degrees of view angle at both 38 °C and 42 °C. The whole standard blackbody system is estimated to have 31 mK and 36 mK uncertainties with coverage factor *k*=2 at 38 °C and 42 °C respectively and is traceable to ITS-90.

REFERENCES

[1] Preliminary Clinical Description of Severe Acute Respiratory Syndrome (http://www.who.int/csr/sars/clinical/en/)

[2] ASTM E1965-98 Standard Specification for Infrared Thermometers for Intermittent Determination of Patient Temperature.

[3] "STEEP 3 version 1.3" User's Guide Virial. Inc.

[4] BS EN 12470-5:2003 Clinical thermometers- Part 5: Performance of infra-red ear thermometers (with maximum device).
[5] JIS T4207: 2005 Infrared ear thermometers.