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REALIZATION OF THE ITS-90 FOR RANGE 232 °C – 962 °C ON KE LP4 AT METROLOGY-LIPI

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Abstract–The realization of ITS-90 has been done at Metrology-LIPI using the radiation thermometer monochromatic KE LP4 80-59 over a temperature range 232 - 962 °C and wavelength λ = 1.57 µm. The method used is Sakuma-Hattori method using fixed-point blackbody tin, aluminum and silver. The value of the uncertainty of the KE LP4 80-59 at the temperature range for the level of confidence of 95% and a coverage factor of k = 2, is expressed by the equation: U (t) = 1.067461375 - 0,008000541.t + 2,586471.10^{-5}.t^2 -3,33928.10^{-8}.t^3 + 1,497270.10^{-12}.t^4.

Keywords: ITS-90 realization, Sakuma hattori Method, radiation, thermometer, monochromatic

1. INTRODUCTION

Metrology-LIPI as National Metrology Institute in Indonesia has been providing infrared thermometer calibration services for many calibration laboratories & industries in Indonesia since 2008. Based on data from infrared thermometer calibration service requested to Metrologi-LIPI, indicate that the largest percentage of the calibrated infrared thermometer is with the measuring range between 50 °C and 1000 °C. The calibration system at 50°C to 500°C consists of a platinum resistance thermometer (Pt-100) as a standard thermometer and a variable temperature blackbody with temperature range from 50 °C to 550 °C as the calibration media. The calibration system at 200 °C to 1000 °C uses a thermocouple type-R as a standard thermometer and a variable temperature blackbody with temperature range from 200 °C - 1200 °C as the calibration media and its traceability range is shown in Fig. 1.

In addition to both of the calibration systems, Metrologi-LIPI also has been providing calibration system for temperature range 1000 °C – 1500 °C, with radiation thermometer as the standard thermometer. The usage of contact thermometer as the standard thermometer for the calibration system at 50 °C - 500 °C and 200 °C - 1000 °C has several factors that can cause a relatively large uncertainty than if the radiation thermometer is used as the standard thermometer in system calibration for temperature range 1000 °C - 1500 °C [1], some of those factors are temperature gradient factor, which is the difference in temperatures because the measurement of the calibration media by standard thermometer and UUT is performed at different locations. Another influential factor is the temperature uniformity and emissivity of the calibration media.

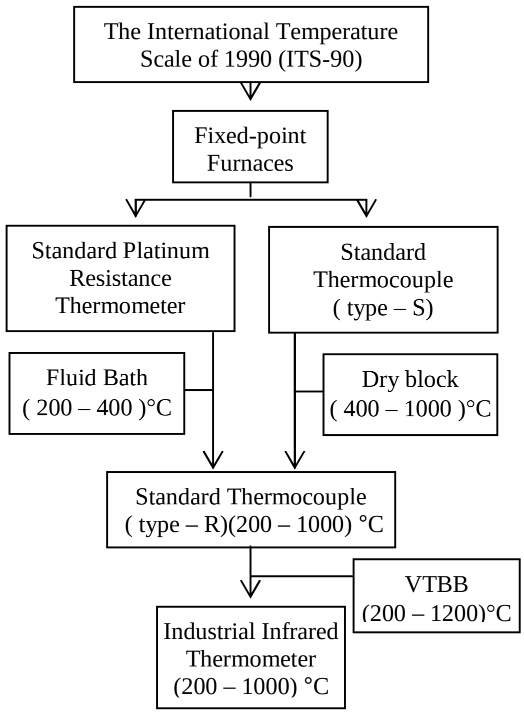

Fig. 1. Infrared thermometer calibration traceability for the temperature range 200 °C - 1000 °C with a thermocouple as standard

Meanwhile if the radiation thermometer is used as the standard thermometer, these factors have very small influence on the measurement results [2]. Therefore to improve the accuracy of the calibration system at 200 °C - 1000 °C, the calibration system with a radiation thermometer as standard has been developed.

The traceability diagram of the infrared thermometer calibration system for temperature range of 200 °C - 1000 °C is shown in Fig. 2. The systems is using radiation thermometer as standard, which is based on equipments that are available at the Research Center for Metrology-LIPI. The shaded box is the box that contains the type of equipment that is already available in the Research Center Metrology-LIPI. From Fig. 2 it can be seen that the calibration system for range 200 ° C - 1000 ° C uses infrared thermometer with measuring range(-50 -1000)°C and spectral response (8-13) µm the standard thermometer. In order to use the infrared thermometer as the standard thermometer in that temperature range, the radiation thermometer must be calibrated against a standard radiation thermometer with measuring range of approximately from 200 °C to 1000 °C. The standard radiation thermometer that can meet these requirements is the radiation thermometer monochromatic which have InGaAs sensor. In this case, the radiation thermometer KE LP4 80-59 [3] owned by Metrologi-LIPI is used.

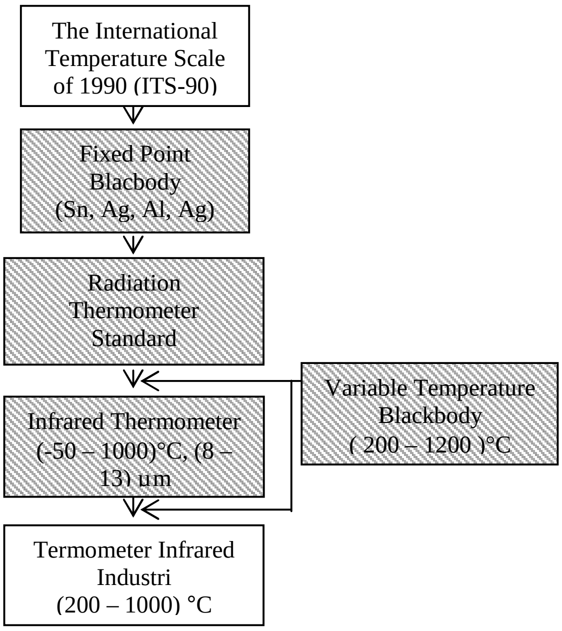

Fig. 2. Infrared thermometer calibration traceability for the temperature range 200 °C - 1000 °C with a radiation thermometer as standard

But the temperature scale of radiation thermometer in this temperature range is not yet adjusted to the ITS-90 (The International Temperature Scale of 1990). Therefore the radiation thermometer has been realized to the ITS-90 for the temperature range between 200 °C - 1000 °C. But the practical reality shows that the radiation thermometer is widely used in temperature range below the point-fixed silver, especially in many industrial applications. When the ITS-90 techniques procedure is used in this temperature range, then there will be difficulties associated with the measurement of the spectral response at infrared wavelength since the radiation thermometer that is used to measure the temperature below the fixed-point silver has a filter at infrared wavelength. However, below silver fixed-point there are many other fixed-points, including the fixed-point of Sn, Zn and Al, which each temperature has been defined in the ITS-90. With the presence of those fixed-points, the temperature scale ITS-90 below silver fixed-point can be applied to the radiation thermometer through the calibration process for the fixed-point followed by derivation of the interpolation equation, which is an equation that connects the output radiation thermometer with a temperature target[2].

Based on the definition of ITS-90, a radiation thermometer is a thermometer that is used to realize the temperature scale above fixed point of silver (961.78 ° C). Realization of ITS-90 on radiation thermometer KE LP4 80-59 is the first step and very important to establish a calibration system with a radiation thermometer calibration range (200-1000) °C. This paper describe the efforts of the realization of the ITS-90 on radiation thermometer LP4 80-59 for temperature range between 200 °C - 1000 °C.

2. INTERPOLATION EQUATION

Based on the Planck’s law of thermal radiation, the equation linking thermometer output signal in ampere, S (T), with a black-body temperature, T is [4]:

$$S(T) = k \int_0^{\infty} R(\lambda).\, L_b(\lambda, T).\, d\lambda \qquad (1)$$

Where:
k = calibration constant
R(λ) = thermometer’s spectral responsivity, ampere
$L_b(\lambda,T)$ = blackbody thermal radiation at wavelength λ and temperature T, $W.A^{-1}.\, str^{-1}.nm$

Usually (1) can be approximated by the Sakuma-Hattori equation [3]:

$$S(T) \approx \frac{C}{\exp\left(\frac{c_2}{AT + B}\right) - 1} \qquad (2)$$

Which is the interpolation equation of radiation thermometer. Equation (2) is the Planckian form of Sakuma-Hattori equation

3. KE LP4 80-59 CALIBRATION

The fixed point blackbodies that are covered in this temperature range 200°C – 1000 °C are fixed point blackbody Tin (t_{Sn} = 231,928°C), Zink (t_{Zn} = 419,527°C), Aluminum (t_{Al} = 660,323°C) and Silver (t_{Ag} = 961,78°C), so that when the radiation thermometer was calibrated against a three of four fixed point blackbodies than the maximum temperature range that can be realized is between 232 °C and 962°C,that’s mean the desired temperature range 200°C – 1000 °C has not been obtained yet.

For temperature range 232 °C - 962°C, the fixed point blackbody Tin, Aluminum and Silver was used as comparator. The calibration scheme is shown in Fig 3.

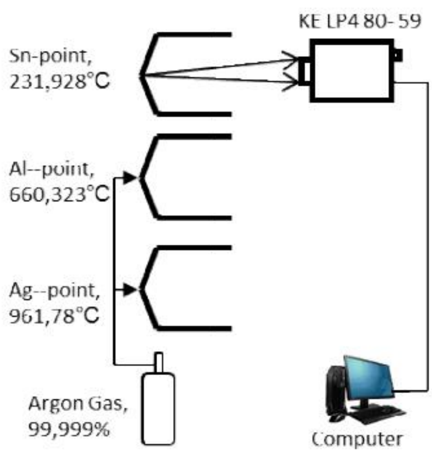

Fig. 3. KE LP4 80-59 Calibration Scheme

The calibration was done sequentially, starting with the calibration by the fixed point blackbody Tin, Aluminum and then the last is Silver. The KE LP4 80-59 calibration results against the fixed point blackbody Sn, Zn, Al and Ag is shown in Table 1.

Table 1. KE LP4 80-59 Calibration Result (λ = 1,57 μm)

Fixed Point	t_{fp}, °C	Range	I_{fp}, A
Sn	231,928	R_1	$1{,}17101.10^{-12}$
Zn	419,527	R_1	$1{,}590456.10^{-10}$
Al	660,323	R_1	$4{,}86255.10^{-9}$
Ag	961,78	R_2	$5{,}366190.10^{-8}$

Because the aperture diameter of the fixed point blackbodies was different, ie Sn and Zn aperture diameter was 12 mm while the opening of Al and Ag was 6 mm, errors due to Size of source effect (SSE) might occur. To avoid this effect, the opening of the fixed-point was normalized to 6 mm diameter openings. Because the measurements also have different instrument range setting, the result then was adjusted according to the range setting. The range ratio value of KE LP4 80-59 with R2 as reference ranges is: R2 / R1 = 1.0009957. The corrected result is shown in Table 2.

Table 2. KE LP4 80-59 Corrected Calibration Result

Fixed Point	t_{fp}, °C	I_{fp}, A
Sn	231,928	$1{,}1717.10^{-12}$
Zn	419,527	$1{,}591363.10^{-10}$
Al	660,323	$4{,}866120.10^{-9}$
Ag	961,78	$5{,}36482.10^{-8}$

The A, B and C constant then was calculated from the corrected calibration resultfor temperature range 232 °C – 962 °C at λ = 1,57 µm, the value are:

A = $1{,}56354.10^{-6}$, m,

B = $1{,}82793.10^{-6}$, m.K ,and

C = 0,00009176631, Ampere.

The correlation between the temperature measured by the KE LP4 80-59 with the current output of the KE LP4 80-59 is shown in Fig. 4.

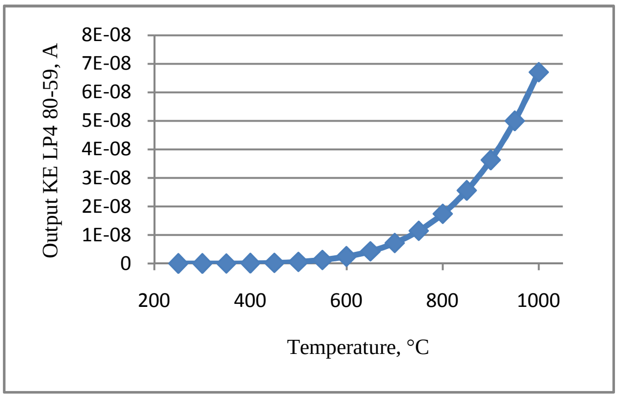

Fig. 4. Correlation profile between temperature and output KE LP4 80-59

To observe the agreement between the temperature scale of KE LP4 80-59 with the definition of ITS-90, the comparison with the redundant fixed-point has been done, ie fixed point that was not used in deriving equations interpolation. The results of the comparison are shown in Table 3 with the difference 0.177 °C.

Table 3. KE LP4 80-59 Corrected Calibration Result

Ampere	ITS-90, îC	Calculation, îC
I_{Zn}= $1{,}58978.10^{-10}$	419,527	419,350

5. UNCERTAINTY CALCULATION

The standard uncertainty equationis:

$$u_c^2(T) = \sum_{i=1}^{N}\left(\frac{\partial S(T)}{\partial T_i}u(T_i)\right)^2 + \sum_{i=1}^{N}\left(\frac{\partial S(T)}{\partial S_i}u(S_i)\right)^2\left(\frac{\partial S(T)}{\partial T}\right)^{-2} \quad (3)$$

Where:

N = number of fixed-pointblackbodies used in the interpolation

$u(T_i)$ = the uncertainty of the standard fixed-point blackbodies number-i

$\partial S(T)/\partial T_i$ = sensitivity coefficients of $u(T_i)$

$u(S_i)$ = standard uncertainty of the radiation thermometer output for the fixed-point blackbodies number-i

$\partial S(T)/\partial S_i$ = sensitivity coefficients of $u(S_i)$

$\partial S(T)/\partial T$ = sensitivity coefficients of $u_c(T)$.

While the total uncertainty from the interpolation is:

$$u_{total}^2(T) = u_c^2(T) + u_{drift}^2(T) + u_{interr}^2(T) + u_{temp}^2(T) \quad (4)$$

Where:

u_{drift} = uncertainty due to the radiation thermometer drift

u_{int_err} = uncertainty due to theinterpolation error

u_{temp} = uncertainty when the thermometer is used

By using the A, B and C value from the calibration result and the calculated uncertainty as well as the value u_{int_err} = 1.6 mK [6], without uncertainty due to drift and the usage of thermometer, then from (2) the uncertainty value of KE LP4 80-59 can be obtained for temperature range 232°C - 962° C with confidence level of 95% and a coverage factor of k = 2, as shown in Table 4.

Table 4. Uncertainty of KE LP4 80-59

t, °C	U, °C	t, °C	U, °C
232	0.23	650	0.30
250	0.22	700	0.28
300	0.21	750	0.26
350	0.23	800	0.25
400	0.25	850	0.26
450	0.28	900	0.30
500	0.30	950	0.40
550	0.31	962	
600	0.31		

To make it easier to determine the uncertainty value of KE LP4 80-59 on any value t of the display, polynomial function in t is calculated with regression method, which is an approximation value of the uncertainty in Table 1. The result is a 4th order polynomial in t as shown in (5).

$$U(t) = 1,067461375 - 0,008000541.t + 2,586471.10^{-5}.t^2 - 3,33928.10^{-8}.t^3 + 1,497270.10^{-12}.t^4 \quad (5)$$

And the chart of the uncertainty approximation value is shown in Fig. 5.

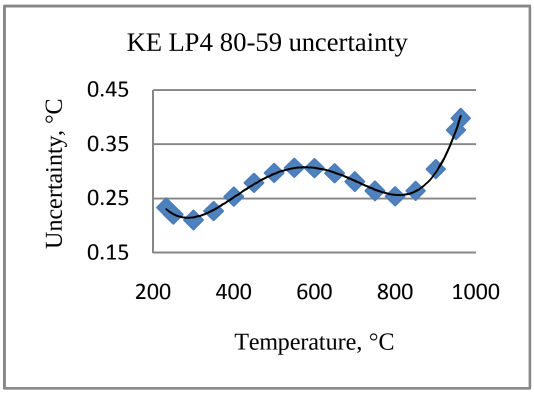

Fig. 5. Chart of the uncertainty approximation value of KE LP4 80-59

The biggest difference between the uncertainty with the approximation value occurs at temperature 900 °C, around 6.4 mK, The uncertainty at that point is 304.04 mK, so the difference is relatively small and can be neglected. Thus we can use (5) as the uncertainty of KE LP4 80-59 for the temperature range 232 ° C - 962 ° C. The difference value between the uncertainty with the approximation value for each temperature value T in the temperature range 232 ° C - 962 ° C is shown in Fig. 6.

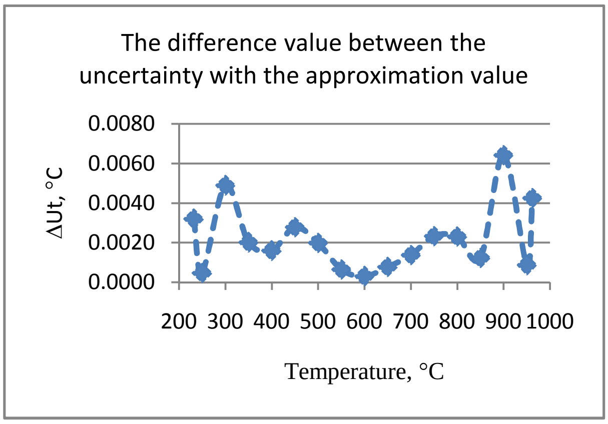

Fig. 6. The difference value between the uncertainty with the approximation value

6. DISCUSSIONS

As an attempt to observe the agreement between the temperature scale of KE LP4 80-59 with the definition of ITS-90, a comparison has been done with the other fixed-point which was not used in deriving equations interpolation (redundant fixed-point). When redundant fixed-point was used as comparator, in this case a Zn fixed-point, the difference was Δt = 0,177°C. Due to the limited number of fixed points that can be used as a comparator, additional efforts will be needed to expand the temperature range of the verification so it can cover the maximum range,f or example, using a variable temperature blackbody which its range covered the temperature range that has been realized in the radiation thermometer and can be monitored with a calibrated contact thermometer.

7. CONCLUSIONS

This work shows Metrology-LIPI has been able to realizing the ITS-90 using the radiation thermometer monochromatic KE LP4 80-59 over a temperature range 232 - 962 °C and wavelength λ = 1.57 µm. Realization of the ITS-90 using KE LP4 80-59 only covers the temperature range between 232 °C and 962°C so it does not meet the desired temperature range between 200 °C and 1000°C. However, this insufficiency can be cover by the system calibration 50 °C – 500°C and 1000 °C – 1500°C. The uncertainty of KE LP4 80-59 referred to the guidelines issued by the BIPM, but the uncertainty components taken from the guidelines still need to be evaluated, which are adjusted to the capacity of the instrument that has been used. Realization of the ITS-90 in KE LP4 80-59 was the first step to build a new calibration system for range between 200 °C up to 1000°C using radiation thermometer as a standard thermometer that will be be calibrated against KE LP4 80-59.

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