BIPM Capacity Building & Knowledge Transfer Programme

2023 BIPM - TÜBİTAK UME Project Placement

REPORT

Project Name	**Development of High Temperature Calibration in Radiation Thermometry**
Description	This project was proposed to obtain better understanding on theoretical, gain the necessary skills and learn the best practices in high temperature measurement and calibration in radiation thermometry as well as to improve the capability and accuracy of the measurement.
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Motivation & Introduction

Currently, NMIM only has the capability to calibrate radiation/IR thermometer from the temperature -30 to 450 ° C and we have the planning to have our own high temperature measurement and calibration in radiation thermometry to cater the demand from Malaysia industries.

Therefore, the project was expected to cover the topics as follows:

1. To learn the calibration of radiation thermometer/Infrared thermometer at higher temperature range (500 to 1000 °C)
2. The measurement of effective wavelength/spectral responsivity.
3. The evaluation of uncertainty for calibration at higher temperature (500 to 1000 °C)
4. To learn the traceability of measurement of radiation temperature using wide wavelength and single wavelength radiation thermometer

I am also interested to learn about calibration of IR thermometer at single wavelength, the effect of SSE and non-linearity on the measurement and factors that contribute to uncertainties of measurement. With this placement, I was also expected to understand the traceability chain for both measurement of radiation temperature using wide wavelength and single wavelength. Besides to enhance the skills to implement best measurement practice in radiation thermometry. With this knowledge, the calibration of radiation/IR thermometer at high temperature range (500 to 1000°C) can be developed and conducted at NMIM.

Project Conducted

At the early time of my placement, I attended the lecture by Dr Humbet for about one week and I have learned a lot on the theory that related to radiation thermometry. The subjects that have been covered were, what is Thermal Radiation, the definition of emissivity, Planck's Radiation Law, ITS-90 Radiation Thermometry Scale as well as The New Kelvin definition and Mise-en-Prattique. During this placement, we also had many discussions to make sure that we could fully understand the topics that we have learned, and Dr Humbet was always willing to answer my questions.

Fig 1: Discussion session conducted by Dr. Humbet NASIBLI, Head of Thermodynamics Metrology Laboratory.

Then we proceed with the calibration of radiation thermometer. For this project, we used temperature calibration system in Thermodynamics Metrology Laboratory of UME which consists of low temperature calibration system, high temperature calibration system with two types of high temperature blackbody, several standard radiation thermometers, and spectral responsivity measurement system. In addition, we are also learned about zinc fixed points and SSE measurement.

Fig 2: Calibration at high temperature using high emissivity blackbody.

For the calibration at 750 °C, Landcal blackbody with maximum temperature of 1200 °C was used as the temperature source and the standard radiation thermometer, TSP1 was used as the standard. Both standard radiation thermometer and UUT were placed at the distance of 38 cm from the aperture of blackbody cavity. The emissivity of UUT and standard radiation thermometer was set at 0.998. Then, the calibration was performed by taking 10 data for both UUT and the standard. To facilitate the calibration process, the calibration software developed by UME was used to collect the data. The data obtained is depicted in Fig 3.

The standard uncertainty of emissivity was also measured by changing the UUT emissivity from 0.998 and 0.997. The uncertainty for SSE is the biggest value (different) from left/right, forward/backward, up/down compares to reading at centre of cavity. Then, based on the obtained data, the uncertainty table was developed shown in Fig 4 below.

	Ref (emiss = 0.998)	UUT (emiss = 0.998)	UUT (emiss =0.997)
1	751.071	749	750
2	751.071	749	750
3	751.070	749	750
4	751.070	749	750
5	751.070	749	750
6	751.070	749	750
7	751.070	749	750
8	751.070	749	750
9	751.070	749	750
10	751.070	749	750
average	751.0702	749	750
std deviation	0.000422	0	0
	emissivity UNC		1
	SSE biggest different val		1
	SSE UNC		0.5

Fig 3: Calibration data at the temperature of 750 °C.

symbol	definition	estimated value	value	distribution	multiplier	standard UNC (xi)	sensitivity coefficient	unc calculation
t_{ref}	Ref Temp value	751.0702	-	-	-			
t_{cal}	reading temp the calibrated value	749	-	-	-			
δt_{ref}	cal unc form calibration cert (ref)	0.00	0.1105	normal	1	0.11	1	0.11
$\delta_{cal\ \_\ stability}$	stability of UUT	0.00	0	normal	1	0.00	1	0.00
$\partial_{ref\ \_\ stability}$	Stability of Ref	0.00	0.000422	normal	1	0.00	1	0.00
$\delta_{resolution}$	resolution of UUT	0.00	0.50	rectangular	0.57735	0.29	1	0.29
δt_{emiss}	emissivity of UUT	0.00	0.5	rectangular	0.57735	0.29	1	0.29
δt_{SSE}	SSE of UUT	0.00	0.50	rectangular	0.57735	0.29	1	0.29
$\delta_{tinterpolation}$	Uncertainty from interpolation (data of UUT)	0.00	0.00	rectangular	0.57735	0.00	1	0.00
$\delta t_{\ repeatibility}$	repeatability of UUT	0.00	0.25	rectangular	0.57735	0.14	1	0.14
$\delta t_{\ reproducibility}$	reproducibility of UUT	0.00	0.25	rectangular	0.57735	0.14	1	0.14
					combined unc		u(Tcal)	0.55
					expanded unc		u(Tcal)	1.10
					declared unc (k=2)		u(Tcal)	1.10

Fig 4: Uncertainty table at the temperature of 750 °C.

Apart from that, we also learned how to convert the temperature at different emissivity based on Sakuma-Hattori equation which is very important in the calibration process of IR thermometer from industries that usually used IR thermometer spectral with response from 8 -14 µm at the emissivity 0.95. Below is an example of calculation of conversion that has been developed in excel.

Table 1: calculation of temperature at different emissivity.

Coefficient Used in Calculation						
c_2	14,387.752	um*K		A	1.5875	um
$\lambda_{\_average}$	1.6	um		B	9.36703	um*K
$\lambda_{\_difference}$	0.2	um		C	1	
Ambient Temp	23	°C	296.15	K		
Dedector Temp	21	°C	294.15	K		

Measured temp (from data of measurement) (°C)	Corrected Temperature value (°C)	Different value in temp (°C)	Measured Temp Value (from measurement data) (K)	S(Tw)	S(Tmeas)	S(Ts)	T (Kelvin)
751.070	750.836	-0.234	1024.220	0.000	0.000	0.000	1023.986
749.000	748.767	-0.233	1022.150	0.000	0.000	0.000	1021.917

Even though the measurement of fixed point was not listed as one of my objectives, I was also taught by Dr Humbet and his staff how to perform the zinc fixed-point measurement. The measurement was conducted using 3 zone furnace which has very good temperature stability. Standard Radiation thermometer with spectral response 1.6 µm was used to observe the melting and freezing plateau of the zinc fixed point. The metal was put inside the quartz cavity with 2 rings of graphite and 7 layers of monolite. Then, the furnace temperature was increased gradually by setting the temperature of furnace at 160 °C, 180 °C, 200 °C, 220 °C and 400 °C. Below is the freezing plateau that has been obtained from the measurement.

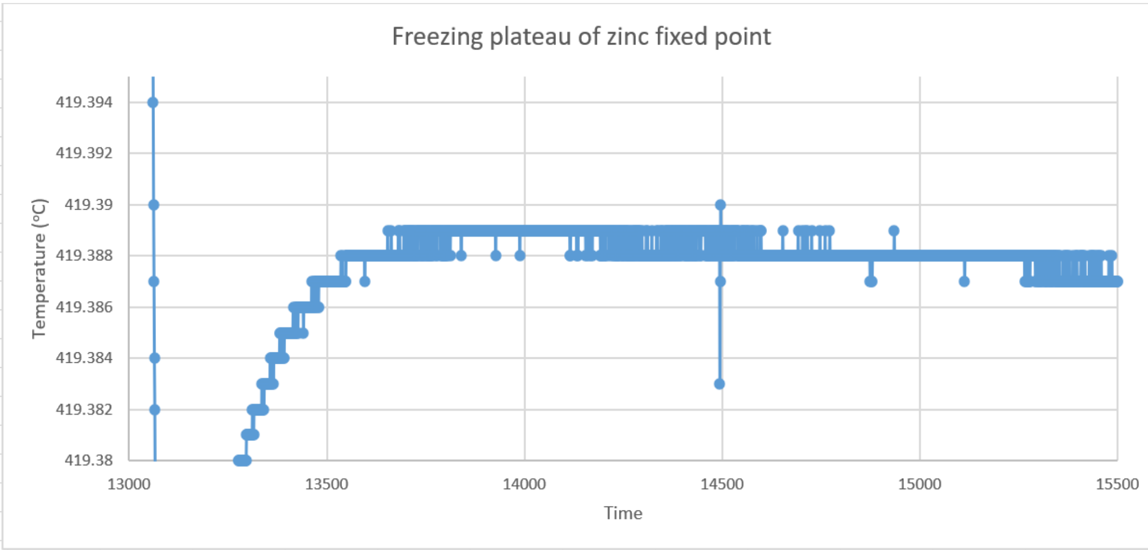

Fig 5: Freezing plateau of zinc fixed point.

For measurement of spectral responsivity, we have used a monochromator which has 5000 slit per 1 cm. Standard Radiation thermometer, TSP2 was placed in front of monochromator and the measurement was taken using the monochromator software. TSP2 spectral sensitivity was measured at 0.1 nm intervals between 880 nm – 950 nm. Then, the data was exported to excel. The half width of maximum was found to be from 892 nm to 923 nm which gave the band width of 31 nm.

Fig 6: Monochromator used for spectral responsivity measurement.

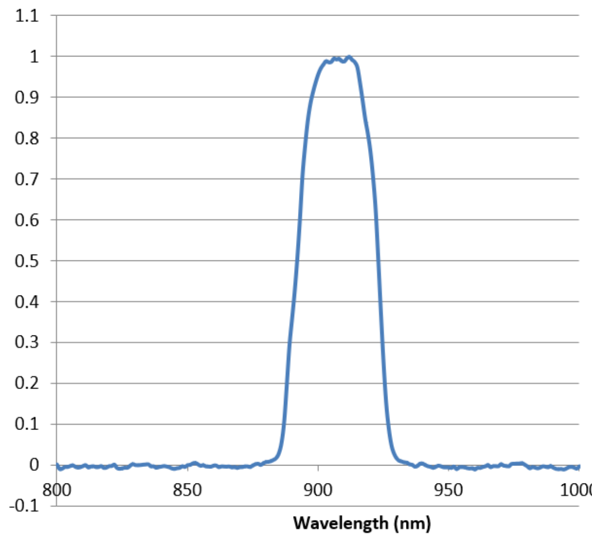

Fig 7: Spectral responsivity measurement.

In addition, I also learned the calibration of flat plate blackbody using Heitronics transfer standard radiation thermometer. The emissivity of UUT and standard thermometer was set at 0.95 and the calibration was done at the temperature 200 °C. The table of uncertainty was also developed, and the figure below shows the calculation of the uncertainty.

CALIBRATION OF IR CALIBRATOR								
UUT	IR calibrator							
ref	Heitronic							
cal temp	200							
Model Function	tref +							
symbol	**definition**	**estimated value**	**value**	**distribution**	**multiplier**	**standard UNC (xi)**	**sensitivity coefficient**	**unc calculation**
t_{ref}	Ref Temp value	196.35	-	-	-			
t_{cal}	reading temp the calibrated value (U	199.944	-	-	-			
δt_{ref}	cal unc form calibration cert (ref)	0.00	0.5	normal	1	0.50	1	0.50
$\delta_{cal\ -\ stability}$	stability of UUT	0.05	0.10298	normal	1	0.10	1	0.10
$\partial_{ref\ -\ stability}$	Stability of Ref	0.10	0.10051	normal	1	0.10	1	0.10
$\delta_{resolution}$	resolution of UUT	0.00	0.01	rectangular	0.57735	0.00	1	0.00
δt_{emiss}	emissivity of UUT	0.00	0.581	rectangular	0.57735	0.34	1	0.34
δt_{SSE}	SSE of UUT	0.00	0.35	rectangular	0.57735	0.20	1	0.20
$\delta t_{interpolation}$	Uncertainty from interpolation (data of UUT)	0.00	0.00	rectangular	0.57735	0.00	1	0.00
$\delta t_{repeatibility}$	repeatability of UUT	0.00	0.05	rectangular	0.57735	0.03	1	0.03
$\delta t_{reproducibility}$	reproducibility of UUT	0.00	0.10	rectangular	0.57735	0.06	1	0.06
					combined unc		u(Tcal)	0.65
					expanded unc		u(Tcal)	1.31
					declared unc (k=2)		u(Tcal)	1.31
SSE								
L/R	U/D	F/B	REPEATIBILITY		0.1			
0.1/0.1	0.7/0.5	0.2/0.1	REPRODUCIBILITY		0.2			

Fig 8: Uncertainty table for calibration of flat-plate black body.

Conclusions and Future Work

As for conclusions, I have learned a lot of things about the calibration of radiation thermometers at high temperature and the measurement of spectral responsivity. Apart from that, I also gained knowledge and skills how to perform fixed point measurements and the calibration of flat-plate blackbody. The conversion of temperature at different emissivity based on Sakuma-Hattori equation is also important and I was very grateful to learn this additional topic. The objectives of my placement were fully achieved and with the knowledge gained, NMIM will be able to offer a new service of calibration of radiation/IR thermometer at high temperature (500 to 1000°C) in the year 2024. This development will also enable NMIM to establish traceability for radiation/IR thermometer in this temperature range. With these capabilities, we also will be able to publish the new scope in Malaysia Standards Accreditation System (SAMM) in year 2024 to 2025. Besides that, with new knowledge and capabilities, I hope NMIM will be able to publish a new CMC in radiation thermometry in KCDB within 5 years' time.

Acknowledgements

I would like to express my appreciation to Mr Chingis KUANBAYEV for accepting me to join BIPM – TUBITAK UME project placement. I also acknowledge my sincere gratitude to Dr. Humbet NASIBLI, Head of Thermodynamics Metrology Laboratory of UME, for giving me the opportunity to learn a lot of things under his supervision and his guidance. I would also like to thank all staff in Thermodynamics Metrology Laboratory and management of UME, for knowledgeable guidance, dedication, and warm friendship. Without their guidance and their dedication, I would not have been able to learn so many topics and thus completed my project during this placement.