Quality Control for Emissive Surfaces

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Abstract

On a flat-plate infrared (IR) calibrator, the surface of the calibrator is the medium that is measured. Generally, this surface is painted. It is very important that this surface be in good condition. A number of checks can be performed to determine the quality of the surface. A visual check is always prudent, but there are other ways to check the quality of the painted surface. One method that has been employed to accomplish this function is to compare measured radiometric temperature and contact temperature.

This paper presents a set of measurements made on an existing product. Both radiometric and contact temperature measurements were made. An inference between emissivity and radiometric temperature is made, and the validity of this inference is shown. The steps taken to improve the quality of this product based on this data is also discussed. The reader of this paper will learn how to employ comparisons between contact and radiometric temperature measurements to verify the consistency of painted surfaces.

1 Introduction

The ideas presented in this paper are the result of an effort in quality control for a current product where paint quality is critical. The 4181 is a precision infrared (IR) thermometer calibrator. It is calibrated with a high-end radiometer [1]. The calibrator's surface is a metal plate that is coated with paint. One of the problems with manufacturing such a product is controlling the consistency of the paint. One method that has been proposed to control this process is to compare radiometric and contact temperature measurements. The comparison would examine the repeatability of these results. The data presented in this paper shows the relationship between these two sets of data. A way to analyze this data for process control is suggested.

2 Theoretical Considerations

The theory that this research is based on involves Planck's Law being applied to an emissive surface (1) [2]. The data used for this study involved taking a large set of radiometric and contact temperature data. Each surface was coated with the same paint. Using Planck's Law, an inference between the repeatability of the radiometric measurement and the repeatability of the surface emissivity was evaluated.

Planck's Law was applied to the spectral response of the radiometer used for this experiment. The spectral response of the radiometer was provided by the manufacturer. By means of numerical evaluation, a relationship between emissivity change and temperature change ($\Delta T/\Delta\varepsilon$) is determined. This relationship is shown in Table 2.

$$E = \int_{\lambda_1}^{\lambda_2} \frac{\varepsilon(\lambda) c_1}{\lambda^5 \left[\exp\left(\frac{c_2}{\lambda T} \right) - 1 \right]} d\lambda \tag{1}$$

3 4181 Calibration

The painted surface used for this experiment was a Fluke – Hart Scientific 4181 Precision IR Calibrator. The data was taken from the 4181's automated calibration [1].

The 4181 Precision IR Calibrator is calibrated radiometrically. This is done using a transfer standard, a Heitronics KT19. The KT19 used in this calibration is an 8-14 µm model. The transfer is done from a series of blackbody cavities [1]. During the calibration, the KT19's emissivity setting is 0.95.

The contact temperature is monitored during the calibration. This is done by a platinum resistance thermometer (PRT) which is located 3mm behind the target's surface. The center of the PRT is centered on the target surface. The purpose of taking contact data is to help diagnose possible problems during the calibration. It does not influence the actual calibration parameters.

4 Correlation of Theory and Practical Data

For this test, 80 data samples were taken at each temperature. These samples were taken over a long period of time. The samples came from more than one batch of painted targets.

These results are shown in Figure 1. There are two sets of horizontal lines on the data. The horizontal line in the middle shows the average of the readings. The two lines above and below the data represent two standard deviations (2σ) of these data sets. The following sections discuss these results.

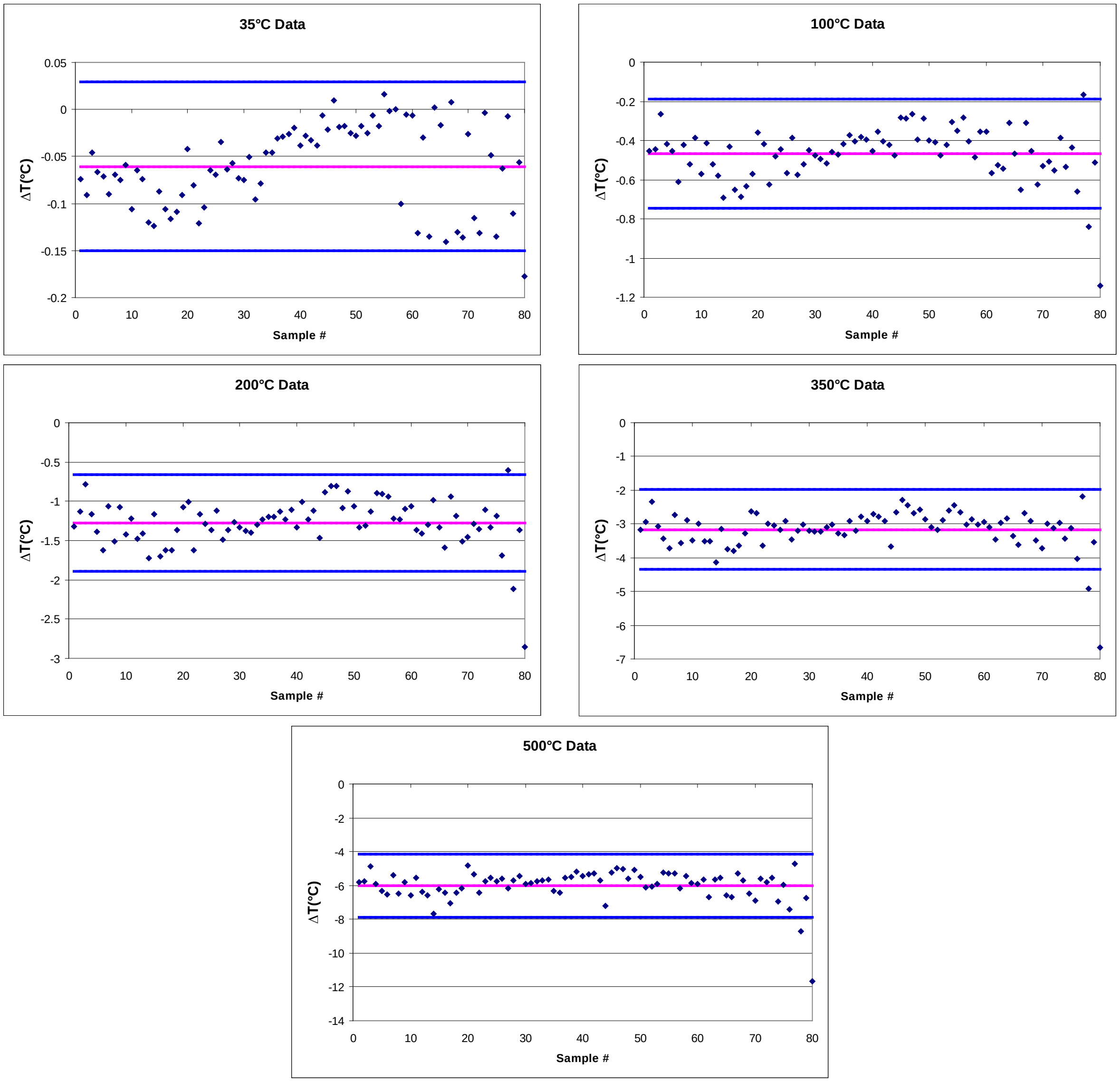

Figure 1: Collected Data

4.1 Uncertainty Budget

The uncertainty budget for this experiment is shown in Table 1. It contains radiometric uncertainty for the KT19 measurements and contact uncertainties for the PRT measurements.

Table 1. Experimental Uncertainties in °C

	35°C	100°C	200°C	350°C	500°C
Radiometric Temperature Measurement	0.11	0.15	0.18	0.21	0.26
Contact Temperature Measurement	0.04	0.05	0.06	0.10	0.13
Combined Expanded Uncertainty (k=2)	0.11	0.16	0.19	0.23	0.29

The radiometric temperature uncertainties are similar to those found in Fluke – Hart Scientific's 4181 and KT19 uncertainty budgets [3]. For the KT19 uncertainty budget, the cavity effects were not considered. This is because the same cavity was used for any calibration of the KT19. Since we are considering repeatability differences and not true temperature, this uncertainty does not need to be considered.

The contact temperature uncertainty analysis is similar to those done for Fluke - Hart Scientific's dry well and metrology well products. It consists of PRT related uncertainty and 4181 controller related uncertainty. The PRT related uncertainties include PRT calibration and characterization, PRT stability (long term), PRT self-heating, PRT stem effect, precision of measurement (noise) and readout accuracy. The 4181 controller related uncertainties include display resolution, hysteresis, repeatability, temperature settling and ambient temperature.

4.2 Correlation between Variation in Radiometric Data and Variation in Emissivity

To analyze the variability in the difference between contact and radiometric data, the temperature repeatability (ΔT) was mathematically converted to emissivity repeatability ($\Delta\varepsilon$) [4]. The data in Table 2 was used to calculate this relationship. This data was also used to calculate the emissivity uncertainty from the temperature uncertainty in Table 1.

Table 2 shows how a variation in emissivity ($\Delta\varepsilon$) corresponds to a variation in measured radiometric temperature (ΔT) when the surface temperature is constant. These numbers are based on numerical modeling of Planck's Equation [5] and are similar to numbers found in published texts [6, 7] and an upcoming standard [8].

Table 2: Emissivity Change and Temperature Change

T (°C)	$\Delta T/\Delta\varepsilon$ (°C/%)
35	0.12
100	0.64
200	1.32
350	2.36
500	3.51

Figure 2 shows the relationship between experimental repeatability and experimental uncertainty. The horizontal solid bars represent the two standard deviations of the 80 samples. The vertical error bars represent the combined expanded uncertainty (k=2) of the experiment.

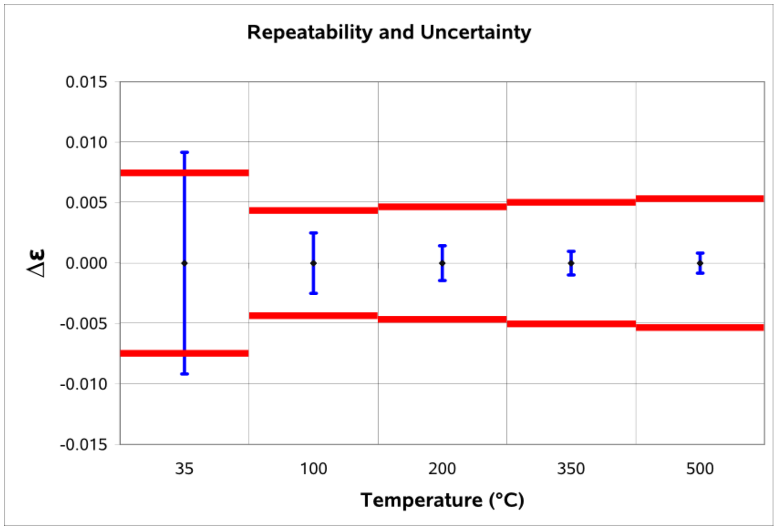

Figure 2: Experimental Repeatability and Uncertainty

5 Conclusion

For higher temperature data, the samples fell within two standard deviations of 0.005 emissivity. At these temperatures, this data was well within the experimental uncertainties shown in Table 1. While there was some variation of the standard deviation of emissivity, the standard deviation values were very similar at any temperature above 100°C.

This data shows that if the proper conditions occur, this technique can be used to determine if a given painted surface falls within a set of emissivity limits. The conditions that need to be maintained are a known stable temperature on the surface and a temperature above 150°C. While this type of test may not reveal as much information as FTIR testing of surface, it could be much less time consuming and less expensive. When performing such an analysis, one should ensure that a complete uncertainty analysis is performed, and the process is properly controlled.

References

1. F. Liebmann, Infrared Thermometer Calibrator Development at Fluke Corporation Hart Scientific Division, Proceedings of SPIE Defense and Security 2008: Thermosense XXX.

2. D.P. DeWitt and G.D. Nutter, Physics of Thermal Radiation and Environmental Effects on Radiation Thermometry, Chapters 1 and 3 in Theory and Practice of Radiation Thermometry, Wiley Interscience, New York, 1988, pp. 41-43.

3. F. Liebmann, Infrared Uncertainty Budget Determination in an Industrial Application, Proceedings of NCSLi 2008.

4. J.A. Wehrmeyer, Basic Concepts, Chapter 3 in U. S. Guide to the Expression of Uncertainty in Measurement, National Conference of Standards Laboratories, Boulder, CO, 1997, pp. 51-58.

5. F. Liebmann, A Study on the Effects of Bandwidth of IR Thermometry Measurements, Proceedings of NCSLi 2009.

6. 1256-95, Standard Test Methods for Radiation Thermometers (Single Waveband Type), Annual Book of ASTM Standards Vol. 14.03, ASTM International, West Conshohocken, PA, 2005, pp. 491-497.

7. Infrared Non-Contact Temperature Measurement, Mikron Instrument Company, No Date Given.

8. ASTM WK21204 - Guide for the Selection and Use of Wide-band, Low Temperature Infrared Thermometers, Work item in progress.