DIAS Infrared Systems

The influence of the emissivity on the non-contact temperature measurement

There are hot objects which are difficult to consider as hot because they emit almost no heat. For example: the small glossy coffeepot in the morning in a hotel which proves to be very hot not until you touch it. This example shows that a non-contact optical temperature measurement has to consider compulsorily the radiation characteristics of the measurement object surface.

Devices for non-contact optical temperature measurement are calibrated by the manufacturer with a black body calibration source which emits the maximum of possible radiation at a specified temperature$(100\ \%\ radiation/emissivity\ \varepsilon = 1)$. This maximum possible radiation is described in Planck’s radiation law [1]:

$$M_{\lambda S} = \frac{c_1}{\lambda^5} \cdot \frac{1}{e^{(c_2/\lambda T)} - 1}$$

$$M_{\lambda 5} \quad Spectral\ radiant\ exitance$$

$$\lambda \quad Wavelength \qquad (1)$$

$$M \quad Absolute\ temperature$$

$$c_1 = 3.74 \cdot 10^{-16}\,Wm^2$$

$$c_2 = 1.44 \cdot 10^{-2}\,mK$$

Figure 1 shows the wavelength dependence of the spectral radiant exitance of black bodies with different temperatures. The lower the temperature the lower gets the emitted thermal radiation. At the same time the maximum of the spectral radiant exitance shifts to higher wavelengths. For temperatures in the range of room ambient temperature this maximum lies in the long-wave infrared range at circa 10 µm wavelength. Temperatures of 1500 °C lead to a maximum radiation in the near infrared range (NIR) at circa 1.6 µm wavelength.

In practice the emissivity is always smaller than 1 so that the real measurement objects emit a lower radiation compared to Planck’s radiation law. Therefor the user has to adjust the emissivity $\varepsilon < 1$ in practice at the device except for a few exceptions. Emissivity values can be found in more or less extensive emissivity tables that are delivered with the devices or which can be found also in the literature [2]. For the most materials and material groups in these tables no fixed values are specified, but only ranges of values. This is due to among other things the fact that the emissivity can depend on the wavelength as well as on the temperature itself, but is also affected by the immediate surface appearance including its time rate of change. A metal surface in process machining for example can change by oxidation or through cooling water.

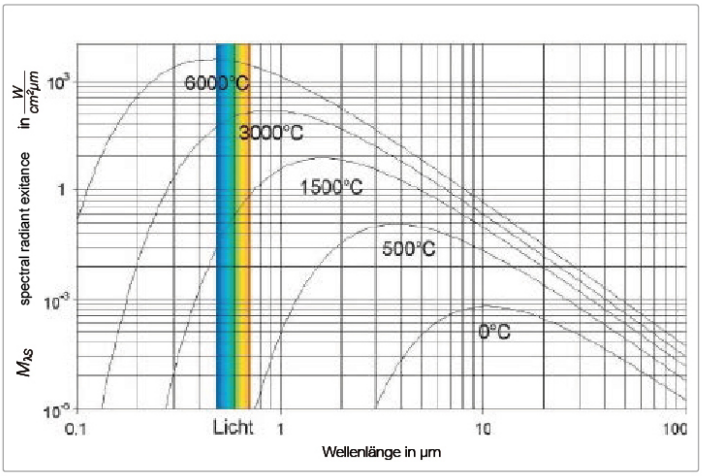

Figure 1:Wavelength dependence of spectral radiant exitance of black bodies of difficult temperature

How does an emissivity misadjustment influence the accuracy of measurement?

It becomes apparent that a precise, error-free emissivity adjustment is not possible at all. The real question there is how an emissivity misadjustment influences the accuracy of measurement. This question can be answered easily with the help of Radiation Physics. Under the marginal condition that the object temperature T_O is much larger than the ambient temperature T_A Planck's radiation law implies:

$$\frac{\Delta T_O}{T_O} = \frac{\Delta \varepsilon}{\varepsilon} \cdot \frac{\lambda_{eff}}{c_2} \cdot T_O \qquad (T_O \gg T_A) \qquad (2)$$

The temperature measurement error ΔT_O depends on the relative emissivity error, the temperature itself and the effective wavelength λ_{eff} and accordingly on the spectral range of the radiation meter. This circumstance is illustrated in figure 2. The temperature measurement errors were calculated at three different object temperatures at an emissivity error of 10 % for four different spectral ranges. It becomes apparent that the error enlarges with increasing measurement wavelength or increasing temperature. Therefor the wavelength range of the measurement device should be at the shortest wavelength possible.

This basic call for measurement at shortest possible wavelengths depends on the other hand on the object temperature. To achieve acceptable temperature resolutions measurement devices with Si infrared detectors (0.8 µm to 1.1 µm) for example that work in very short wavelengths can be applied only from 600 °C. The relative emissivity error also depends on the general emission level. If a steel surface ($\varepsilon = 0.85$) is measured with $\varepsilon = 0.8$ the emissivity is adjusted wrongly with a percentage of 6 %. So a device with Si detector would display 3 °C too much at 600 °C. If the temperature on a tungsten surface ($\varepsilon = 0.35$) is measured with $\varepsilon = 0.3$ at the same temperature (600 °C), the emissivity is adjusted wrongly with a percentage of 14 % and the measurement device displays 8 °C too much. Though the emissivity level of metal surfaces decreases more and more in the long-wave range specifically metals should be measured at the shortest possible wavelength.

Spectral range	$T_O = 600$ °C		$T_O = 800$ °C		$T_O = 1200$ °C	
	ΔT_O	$\Delta T_O/T_O$	ΔT_O	$\Delta T_O/T_O$	ΔT_O	$\Delta T_O/T_O$
0,8 µm to 1,1 µm	5 °C	0,9 %	8 °C	1,0 %	15 °C	1,3 %
1,5 µm to 1,8 µm	9 °C	1,5 %	13 °C	1,7 %	25 °C	2,1 %
3 µm to 5 µm	20 °C	3,4 %	30 °C	3,8 %	57 °C	4,8 %
8 µm to 14 µm	48 °C	7,9 %	72 °C	9,0 %	136 °C	11,3 %

Figure 2: Temperature measurement error **ΔT_0** and relative temperature measurement error **$\Delta T_0/T_0$** at an emissivity error of 10 % in dependence of object temperature and spectral range

More than standard only

Infrared measurement devices for non-contact measurement of the mid temperature of a measurement field go by the name of radiation thermometers or pyrometer. If the measurement field is small enough the devices are called devices for point temperature measurement. Measurement devices of renowed manufacturers are offered today with a lot of variants that provide an optimal choice of spectral range and temperature range. The same laws apply for thermal imaging devices accordingly infrared cameras for non-contact measurement of temperature distributions including infrared line cameras for the measurement of temperature profiles. Nevertheless there are less manufacturers that provide devices beyond the “standard” spectral range of 8 µm to 14 µm. DIAS Infrared from Dresden (Germany) is one of those manufacturers that provide industrial temperature process technology in an manifold product range.

Literature:
[1] VDI/VDE-Richtlinien 3511, sheet 4, Technische Temperaturmessung – Strahlungsthermometrie, Berlin, Beuth Verlag, 2011-2012
[2] VDI/VDE-Richtlinien 3511, sheet 4.5, Technische Temperaturmessung – Strahlungsthermometrie in der Praxis, Berlin, Beuth Verlag, 2013

Authors:
Dr. Christian Schiewe, System and application engineer
Katrin Schindler, Marketing & PR

Contact:
DIAS Infrared GmbH, Dresden
Tel.: +49 351 896 74-0, Web: www.dias-infrared.com

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