BLACKBODY Technical Note

Improving cooling of cavity blackbodies

A cavity blackbody is the appropriate IR reference source for IR sensors which require high radiance levels. It combines high emissivity independent from wavelength and high speed warm up and high stability thanks to its light trap structure. However, the inconvenient of this structure is that it leads to a prohibitive cooling time. HGH developed a method to speed up the cooling time.

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GENERALITIES ON BLACKBODIES

Calibrating and measuring specifications of IR sensors require the use of infrared reference sources, known as blackbodies, which optical radiation only depends on their temperature according to the Planck's law. At thermal balance, another important property of blackbodies is that they absorb all incident radiations whatever their wavelength.

Usual objects are not blackbodies: they partially absorb a fraction $A(\lambda)$ of the incident radiation, they reflect a fraction $R(\lambda)$ of this incident radiation and transmit a fraction $T(\lambda)$.

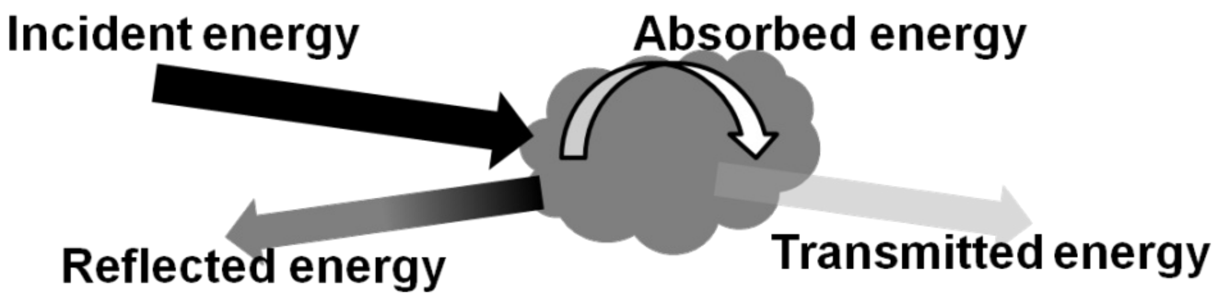

Figure 1 - distribution of incident energy on usual objects.

Since the fraction $A(\lambda)$ is re-emitted through radiation, an emission factor $\varepsilon(\lambda)$, called emissivity, is defined to quantify the ability of a body to re-emit this radiation. At thermal balance, $A(\lambda) = \varepsilon(\lambda)$.

$$\varepsilon(\lambda) + R(\lambda) + T(\lambda) = 1 \qquad \text{(eq. 1)}$$

Consequently, for a true blackbody the above equation becomes:

$$\varepsilon(\lambda) = 1 \text{ whatever the wavelength} \qquad \text{(eq. 2)}$$

However, such bodies don't exist and manufacturing IR reference sources consists in creating sources with emissivity value as high and as constant as possible over the widest spectral range. These sources are called grey bodies but practically for sources with emissivity higher than 0.9, these sources are called blackbodies.

Depending on the applications and on the IR sensor range of sensitivity, the manufactured blackbodies are divided into 3 families usually defined by their temperature range:

- Low temperature extended area blackbodies, which temperature is set from approximately -40°C to more than 150°C
- High temperature extended area blackbodies, which temperature is set from above ambient temperature up to 600°C
- High temperature cavity blackbodies, which temperature is set from above ambient temperature up to more than 1200°C

The emissive area of the first two families is covered with high absorptive black paint or coating sometimes combined with grooved or micro-cavity shaped emissive surface. Such blackbodies have an approximately constant emissivity up to 0.99 over a spectral range covering the MWIR and LWIR (i.e. 3-5 µm and 8-12 µm).

For temperatures above 600°C-700°C, high absorptive paints and coatings are damaged and cannot be used. Hence, the basic property of the blackbody, i.e. it absorbs all incident radiation, is put into practice to manufacture the third family of blackbodies, high temperature cavity blackbodies.

CAVITY BLACKBODIES: DESCRIPTION AND FEATURES

A cavity blackbody operates as a light trap: incident rays entering though the small aperture reflects on the internal surfaces of the cavity. Since the cavity surface already has an intrinsic high emissivity (usually about 0.9), the incident radiation is partially absorbed every time it reflects on the cavity surface. Indeed, this reflection is diffuse. Finally very few incident radiation escapes from this light trap.

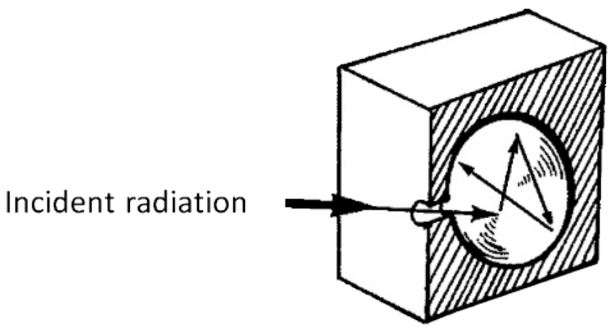

Figure 2 - light trap principle.

By comparison with primary standard IR reference sources, the emissivity of HGH's cavity blackbody is higher than 0.985 over 1 to 3 µm spectral band and higher than 0.99 above 3 µm.

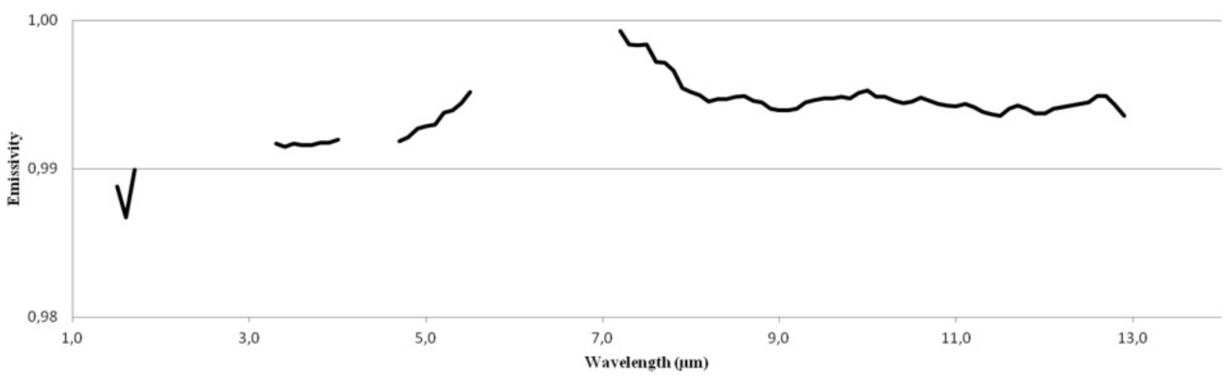

Figure 3 - emissivity curve of a cavity blackbody [1] .

[1] Calculated from the calibration certificate number K021353 of the LNE (Laboratoire National d'Essai) over a HGH's cavity blackbody RCN1200N1

Since no painting or coating is put on the cavity surface, this light trap effect is independent from the wavelength leading to a constant emissivity over the whole IR spectral range.

This cavity is surrounded by a set of heaters, heating the cavity to very high temperatures. The temperature of the cavity is measured and controlled in real time through a thermocouple sensor. A refractory casing around the heaters limits the losses through conduction. A double surface cover allows the external cover of the source to remain at room temperature while the temperature of the cavity is 1200°C.

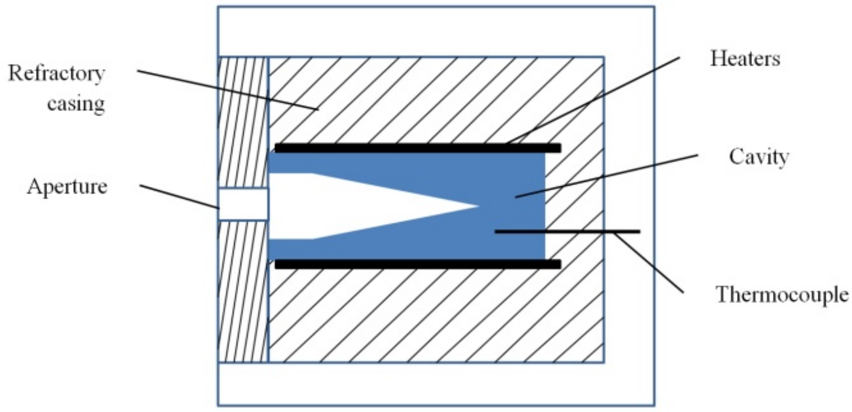

Figure 4 - cavity blackbody structure.

In addition to a high emissivity as explain above, this configuration leads to other interesting specifications: high speed warm up and high stability, as described hereafter.

This structure has very few thermal losses. The thermal losses are made through radiation, convection and conduction.

- Radiation losses power is given by the Stefan-Boltzmann law:

$$P_{rad}=\sigma \cdot A \cdot (T^4 - T_{amb}^4) \qquad \text{(eq. 3)}$$

where σ is Stefan constant, σ=5.67 10^{-12} W/cm²/K⁴, A is the output area of the cavity and T is the temperature of the cavity in Kelvin.
In the case of a cavity at 1200°C with 25 mm diameter aperture, P_{rad}= 130W.

- Convection losses are through natural convection only over the area of the cavity:

$$P_{conv}=h \cdot A \cdot (T-T_{amb}) \qquad \text{(eq. 4)}$$

where h is the thermal exchange coefficient and approximately equals 5 W/m²/°C. In the above example, P_{conv}=3 W.

- Conduction losses toward refractory casing along the cavity length is

$$P_{cond}=(\lambda \cdot S/e) \cdot (T-T_{amb}) \qquad \text{(eq. 5)}$$

Where λ is the thermal conductivity of the refractory casing and equals 0.1 W/m/K. S/e is the ratio between the cavity external area and the thickness of the refractory casing and equals 0.54 m. In the above example, P_{cond}=65W.

The power of the heaters is 1400W. This power is necessary to heat the cavity up to the maximum temperature of the blackbody and to compensate for the above losses, once it is stabilized.

The power of the heaters is much higher than the losses. This leads to two properties of these cavity blackbodies: high speed rising time to maximum temperature and a high stability of regulation thanks to the combination with a reactive PID regulator.
The example below shows the temperature of the cavity versus time from starting point at ambient temperature up to 1200°C.

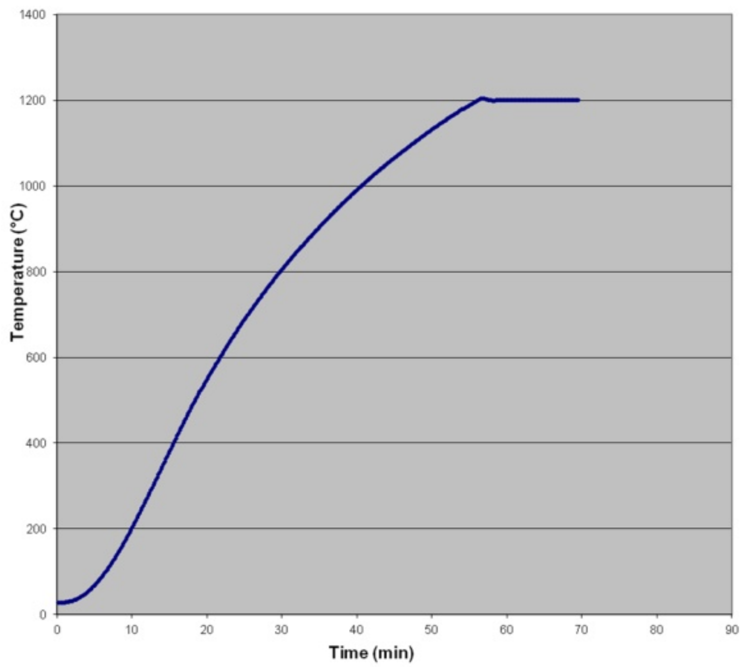

Figure 5 - rising time from ambient temperature to 1200°C.

Rising time from ambient temperature to 1200°C ±0.5°C is less than 1 hour.

Once the cavity has reached a temperature, the temperature remains stable over time within less than 0.1°C rms. See below example of cavity temperature during 10 minutes at 900°C.

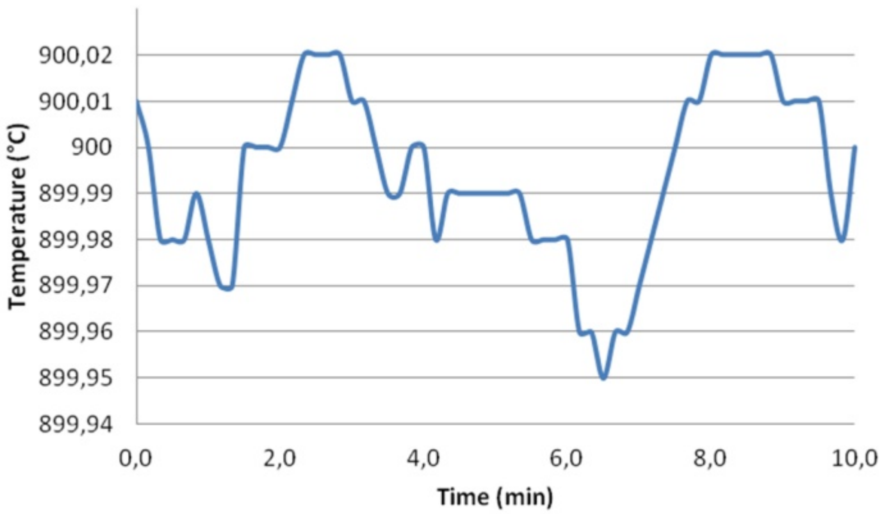

Figure 6 - example of stability curve of the temperature over 10 minutes at 900°C.

The advantage of such a high stability is that it allows the measurement of the noise (such as NETD measurement) of high-end IR sensors to comply with the 4:1 ratio law, saying that a reference equipment should have less than 1/4 of the measurement uncertainty of the tested device.

As mentioned above, the thermal losses through radiation, convection and conduction are about 200W when the cavity is at 1200°C. The total energy of a cavity at 1200°C is evaluated to 2.10^3 kJ. If the losses were constant during cooling, it would take 3 hours to cool down the blackbody to ambient temperature. However, the thermal losses depend on the temperature difference between the cavity and the ambient temperature, as shown from equations (3) to (6), and decrease at least as fast as the temperature of the cavity decreases. As a consequence, the cooling time down to temperature about 50°C is then more than 5 hours as shown on Figure 7.

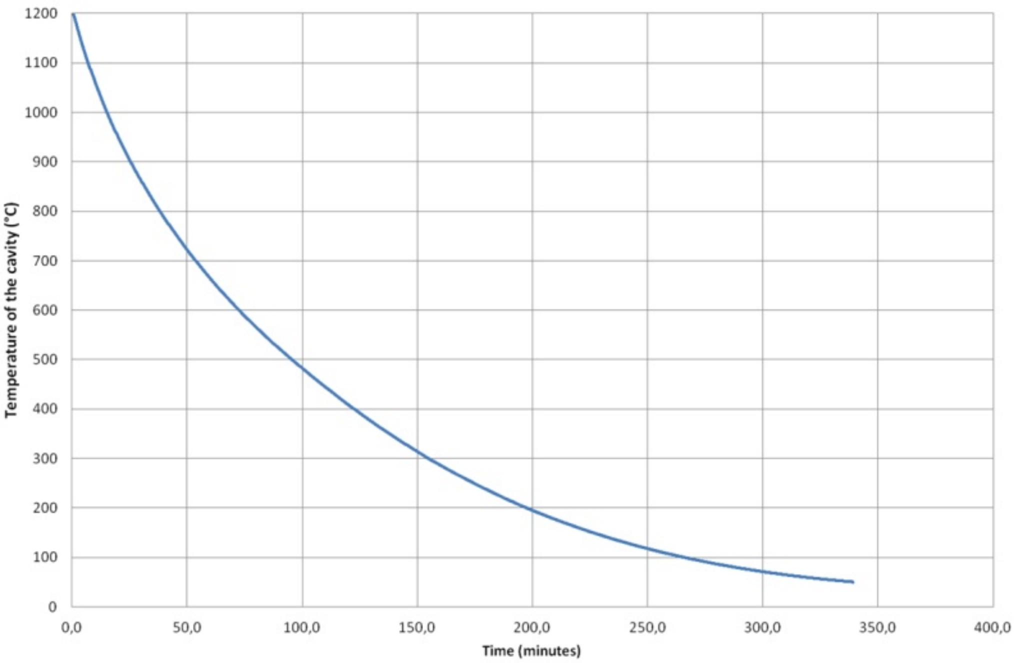

Figure 7 - Cooling curve of a cavity blackbody from 1200°C.

Practically, because of this long cooling down time, calibration and testing procedures of IR sensors have to start from low temperatures to high temperatures. This operating constraint is no longer acceptable by blackbodies users and HGH decided to modify its cavity blackbodies to significantly decrease cooling down time.

COOLSPEED SYSTEM

Decreasing cooling time requires increasing thermal losses. However this improvement should not alter main features of the cavity blackbody: emissivity, high speed heating time, high stability. Increasing thermal losses through radiation requires increasing the aperture of the cavity: this would mainly affect the emissivity of the source. Increasing thermal losses through conduction would lead to heat the external structure of the blackbody: this is not acceptable since it would potentially create danger of burning for the operator. Besides, it would strongly affect the stability of the source.

Consequently, it has been decided to increase thermal losses through convection. Indeed, as noticed from equations (3) to (5), thermal losses through convection were previously negligible compared to other thermal losses through conduction and radiation. The internal structure of the cavity blackbody has been improved to allow heat evacuation through convection. This modification is called CoolSpeed system. The CoolSpeed system is driven from the blackbody controller. The controller has the possibility to activate or inhibit this system.

Thermal losses through convection were previously evacuated through 2 fans located at the back face of the blackbody. This evacuating system remains unchanged with the CoolSpeed system. However during the tests, a thermocouple is located at the output of each fan to measure the temperature of the evacuated heat. To limit the temperature of the evacuated air to acceptable values, the CoolSpeed system is activated only below 700°C. Indeed, the gain on the cooling speed due to CoolSpeed system is not significant above 700°C since the “classic” thermal losses, i.e. mainly radiation losses, are high.

The temperature of the cavity is measured while cooling down in the above conditions (see Figure 8).

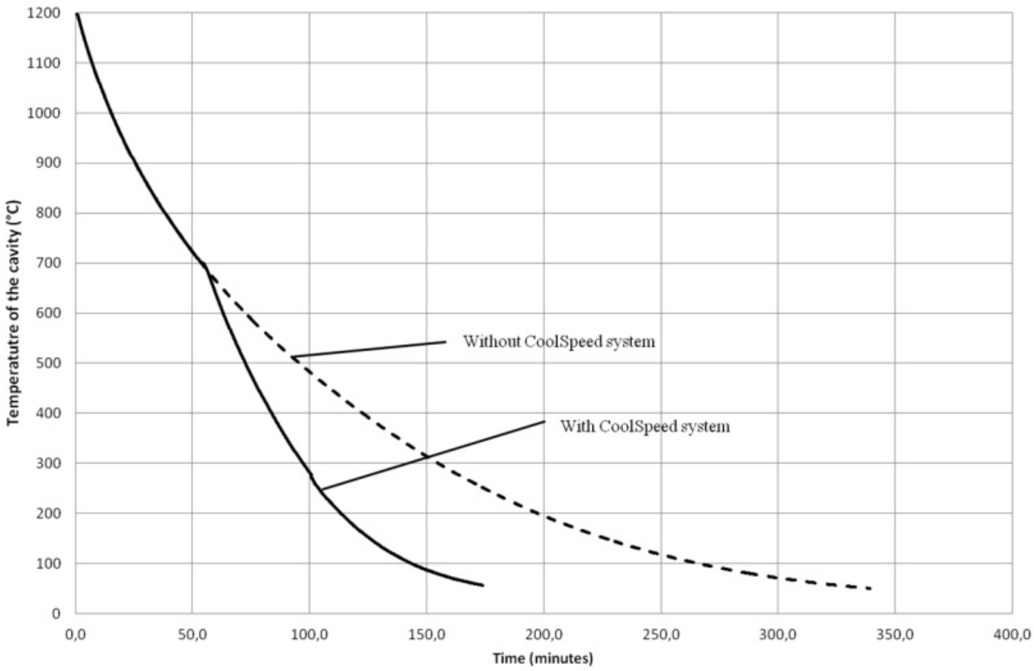

Figure 8 - Cooling curve of a cavity blackbody from 1200°C without and with CoolSpeed system.

In this case the maximum output temperature of the evacuated air is 50°C and the cooling down time from 1200°C to ambient temperature is about 3 hours instead of more than 5 hours (see previously Figure 7). Moreover if the initial temperature is 700°C, the cooling time to ambient temperature is then divided by more than 2 compared to the cooling time without CoolSpeed over the same range.

If the operator requires to stop at another temperature setpoint (for example 300°C), the CoolSpeed function is automatically inhibited below this temperature and outside the amortization range (in the above example at about 275°C). Then, the classical heating and PID regulation loop is operated to heat up to the required setpoint: the initial features (emissivity, stability, warm up time, etc.) of the blackbody are then not damaged by the CoolSpeed system.

CONCLUSION

HGH Infrared Systems is offering a new way of working to engineers using high temperature cavity blackbody as reference sources to characterize and calibrate near-IR and IR sensors. Until now, the particularly long thermal inertia of this kind of devices, key elements in characterization benches, has had to be taken into account in test strategy. It could contribute to major shift in projects schedules, in case of unexpected results during test campaigns. HGH Infrared Systems has developed an innovative internal structure on its best-selling RCN1200N1 blackbody to highly reduce its temperature stabilization time. The CoolSpeed system divides by approximately 2 the cooling duration of a cavity blackbody without altering its technical features such as high emissivity, high speed warm up and high stability. Now, with cavity blackbodies equipped with CoolSpeed, it is no longer necessary to calibrate systems exclusively by increasing temperatures. CoolSpeed brings high flexibility to users, especially in the context of Research and Development projects.

REFERENCES

[1] Gaussorgues, G., [Infrared Thermography], Chapman & Hall, London, chapter 3 (1994)

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