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Emissivity measurement for infrared thermography and radiative exchanges

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Abstract

Several methods of measuring emissivity are presented. Emphasis is placed on directional emissivity measurements necessary for quantitative measurements by infrared thermography. For instance, 0.01 variation for on a given emissivity of 0.9 will induced a temperature measurement error of 0.75K at 300K and 2.5K at 1000K. The case of dielectrics and metals are treated and a presentation allows to know the different measurement methods. Laboratory and field methods are presented as well as commercial devices available on the market.

1 Introduction

There are many scientific and technical fields where knowledge of surface emissivity is required. Emissivity is essential for calculating and optimising heat exchange by radiation. Remote temperature measurement by optical pyrometry or thermography and remote detection of objects, heat sources and targets are also common applications requiring knowledge and control of the emissivity of materials. The emissivity of a material depends strongly on the nature of the material, it can also depend on the wavelength, surface morphology (roughness) and temperature. Numerous emissivity data are available in the technical and scientific literature for many materials but the numerical values found can be extremely scattered for the same material. This is often due to the fact that the materials tested were slightly different (e.g. a more or less oxidised metal) or that the surface conditions were different. For the user, the only reliable solution to obtain reliable emissivity data is therefore often to measure the emissivity on the material used. This document first provides a very basic understanding of thermal radiation, definitions of the most commonly used emissivities (directional or hemispherical emissivity, spectral or total emissivity) and the relationships between the radiative properties of materials and between normal and hemispherical emissivity. This document also presents commercially available emissivity measurement instruments and the main valid standards dealing with emissivity measurements.

2 Definitions of the different emissivities

Material surfaces can exchange energy in the form of radiation. The amount of energy that a surface can emit depends on its temperature and nature. Planck's law specifies the spectral luminance for a theoretical surface called a black body:

$$L_0(\lambda,T) = \frac{2\cdot h\cdot c^2}{\lambda^5\cdot\left(e^{\frac{h\cdot c}{\lambda\cdot k\cdot T}}-1\right)} \qquad (1)$$

where h = 6.62617.10-34 J.s is Planck's constant, c is the speed of light in the medium considered (we will take the value of c in a vacuum: c = 299792458 m.s-1) and k = 1.38066.10-23 J.K-1 is Boltzmann's constant. The spectral radiance L_0 is expressed in W.m^{-3} .sr^{-1} .
For a real material, this luminance is weighted by a factor between 0 and 1 called emissivity. It is noted ε.
This coefficient can depend on the wavelength, direction and temperature: $\varepsilon(\lambda,T,\theta,\varphi)$.
Emissivities are classified according to the spatial and spectral ranges of radiation. Total emissivity is the emissivity calculated over all wavelengths and monochromatic emissivity is the emissivity calculated for a single wavelength. Hemispheric emissivity is the emissivity calculated for all directions and directional emissivity is the emissivity calculated for one direction only.

2.1 Monochromatic directional emissivity

The monochromatic directional emissivity, denoted $\varepsilon_\lambda^{|}$ is the ratio between the luminance of the material, for a given direction and wavelength, and that of the black body. It is the quantity that allows the most accurate description of the radiation emitted by a given material, with the angles defined according to the Figure 1 ***Geometric definition of angles***:

$$\varepsilon_\lambda^{|}(\lambda,T,\theta,\varphi) = \frac{L_{Matériau}(\lambda,T,\theta,\varphi)}{L_0(\lambda,T)} \qquad (2)$$

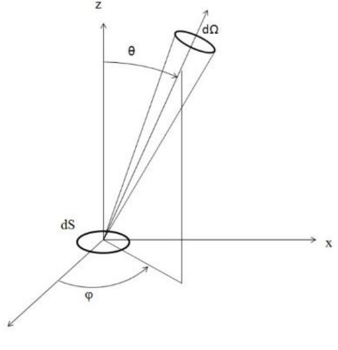

Figure 1 *Geometric definition of angles*

Most materials have an emissivity that does not depend on orientation and therefore does not depend on the angle ϕ. For smooth surfaces this emissivity may depend on the polarisation of the light.

2.2 Total directional emissivity

The total directional emissivity is the ratio of the luminance radiated by the surface of the material to the luminance radiated by the black body over the entire electromagnetic spectrum:

$$\varepsilon^{|}(T,\theta,\varphi) = \frac{\int L_{Matériau}(\lambda,T,\theta,\varphi)\cdot d\lambda}{\int L_0(\lambda,T)\cdot d\lambda} \qquad (3)$$

2.3 Broadband directional emissivity

This concept is essential for users of "broadband" optical pyrometers or thermal imaging cameras that use a spectral band that is not narrow but does not cover the entire emission spectrum. Typically thermal imaging cameras and pyrometers use two bands of atmospheric transparency: 3 to 5µm and 8 to 14µm. It may therefore be useful to know the emissivity in this band:

$$\varepsilon^{|}_{\lambda_1,\lambda_2}(T,\theta,\varphi) = \frac{\int_{\lambda_2}^{\lambda_1} L_{Matériau}(\lambda,T,\theta,\varphi)\cdot d\lambda}{\int_{\lambda_2}^{\lambda_1} L_0(\lambda,T)\cdot d\lambda} \qquad (4)$$

This value of emissivity is of interest to users of thermal imaging cameras. It allows the luminance in one direction to be related to the temperature. This calculation or measurement of emissivity can be done in a wavelength band identical to that of the camera or in a given spectral band. In order to be completely accurate, the sensitivity of the camera's detector should be taken into account as a function of wavelength in order to determine the temperature.

2.4 Total hemispheric emissivity

The total hemispherical emissivity, ε, is the ratio of the total hemispherical emittance of the material to that of the black body for all wavelengths at a given temperature:

$$\varepsilon = \frac{\int L_{Matériau}(\lambda,T,\theta,\varphi)\cdot sin\theta\cdot d\theta\cdot d\varphi}{\int L_0(\lambda,T)\cdot sin\theta\cdot d\theta\cdot d\varphi} \qquad (5)$$

This emissivity is usefull when carrying out heat balances between opaque walls. It allows the calculation of radiative exchanges between surfaces at different temperatures.

3 Calculation of emissivity from the complex index

Relation 6, based on the principle of conservation of energy, relates for a given wavelength the spectral hemispherical directional transmittance, the spectral hemispherical directional reflectance and the spectral directional absorptance.

$$\alpha(\lambda) + \tau(\lambda) + \rho(\lambda) = 1 \qquad (6)$$

where α is the spectral absorption factor, τ the spectral hemispheric directional transmittance and ρ the spectral hemispheric directional reflectance.

For an opaque material, Kirchhoff's law states that the spectral directional absorption factor is equal to the spectral directional emissivity. This law combined with relation 6 for an opaque material leads to :

$$\varepsilon(\lambda) = 1 - \rho(\lambda) \quad (7)$$

Relation 7 is the basis for indirect methods of measuring spectral directional emissivity. It allows the emissivity to be calculated from the spectral hemispherical directional reflectance, which in turn can be calculated using the Fresnel relations. This approach is only valid for diopters, i.e. for smooth surfaces.

3.1 Calculation of emissivity for both polarisations of light

For the plane diopter, the emissivity can be calculated from the expression of the reflection coefficients, calculated from the complex index, ***n = n₀ +i.χ***. This detailed calculation can be found in [1] from Maxwell's equations. These expressions are deduced from the Fresnel coefficients for reflection, and can be found in [2]. Equations 8 and 9 can be used with complex indices, which allows them to be used for the calculation of the emissivity of metals.

For unpolarised light, the arithmetic mean of the two emissivities corresponding to the two polarisations must be taken. The expressions for the two emissivities for the two polarisations are shown below:

$$\epsilon_{/\!/} = 1 - \left\| \frac{\left(n\cdot\cos(\theta) - \sqrt{1-\frac{\sin(\theta)^2}{n^2}}\right)}{\left(n\cdot\cos(\theta) + \sqrt{1-\frac{\sin(\theta)^2}{n^2}}\right)} \right\|^2 \qquad (8)$$

And

$$\epsilon_{\perp} = 1 - \left\| \frac{\left(\cos(\theta) - n\cdot\sqrt{1-\frac{\sin(\theta)^2}{n^2}}\right)}{\left(\cos(\theta) + n\cdot\sqrt{1-\frac{\sin(\theta)^2}{n^2}}\right)} \right\|^2 \qquad (9)$$

The normal directional emissivity can also be calculated ε_nIn this case the two polarisations are equivalent and the following result is obtained for a complex index n:

$$\varepsilon_n = \frac{4\cdot n_0}{(n_0+1)^2+\chi^2} \qquad (10)$$

3.2 Case of dielectric materials

The *Figure 2* from [1] shows the directional emissivity as a function of angle for a dielectric with a refractive index of 1.5:

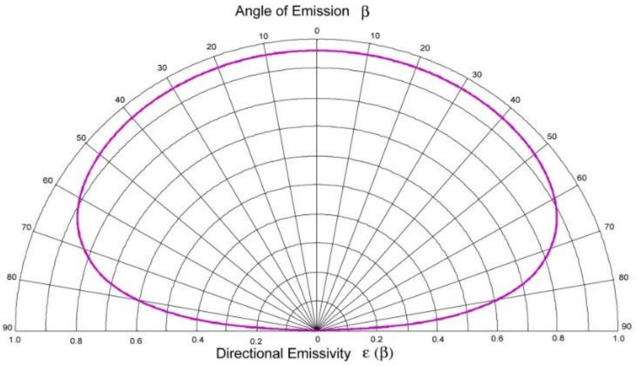

Figure 2 *Directional emissivity as a function of angle for a dielectric with a refractive index of 1.5* **[1]**

3.3 The case of metals and electrically conductive materials

In the same way, the emissivity indicator can be plotted for an air/metal diopter. This gives a theoretical emissivity indicator similar to what can be obtained for a metal such as aluminium. The one shown *Figure 3* from [1] is calculated for a typical refractive index of a metal such as aluminium: n = 5.7 + 9.7i.

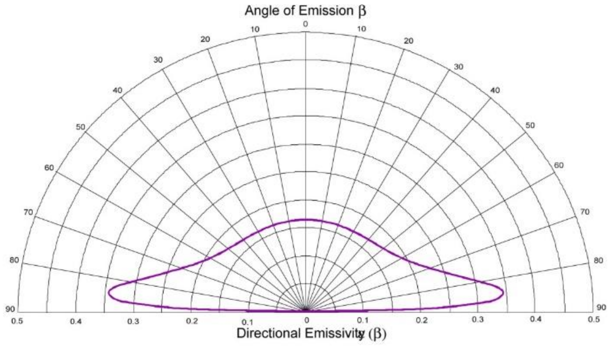

Figure 3 *Directional emissivity as a function of angle for a metal with refractive index: n = 5.7+9.7. i*

3.4 Relationship between normal directional emissivity and hemispheric emissivity

Directional emissivity is frequently measured for technical convenience in the near-normal direction. However, it is often necessary to obtain the hemispherical emissivity. The hemispherical emissivity is the integration of the directional emissivity over all useful solid angles. If it is not possible to measure the hemispherical emissivity for all directions, it must be possible to deduce the hemispherical emissivity from the quasi-normal directional emissivity. The values of Table 1 are taken from ISO 12898.

Table 1 *Factors for calculating the total hemispheric emissivity from ε_n for a smooth dielectric surface*

Total emissivity at normal incidence ε_n	0.03	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.89
Ratio $\varepsilon/\varepsilon_n$	1.22	1.18	1.14	1.1	1.06	1.03	1	0.98	0.96	0.95	0.94

A few notable studies have documented this coefficient $\varepsilon_\cap/\varepsilon_n$. For smooth surfaces with low emissivity (typically metals). Rubin and Hartmann [3] used silver and In_2O layers on glass. An analytical expression was obtained using experimental data and Kramers-Kronig relations:

$$\frac{\varepsilon_\cap}{\varepsilon_n} = 1.3217 - 1.8766\cdot\varepsilon_n + 4.6586.\varepsilon_n{}^2 - 5.8349.\varepsilon_n{}^3 + 2.7406.\varepsilon_n{}^4 \qquad (11)$$

Equation (12) is valid for emissivities ranging from 0.65 to 0.98 for dielectric materials [3] [4]

$$\frac{\varepsilon_{\cap}}{\varepsilon_n} = 0.1569 + 3.7669 \cdot \varepsilon_n - 5.4398 \cdot {\varepsilon_n}^2 + 2.4733 \cdot {\varepsilon_n}^3 \qquad (12)$$

These data are consolidated and enriched in two European research reports [5] [6]. They provided the data necessary for the drafting of the ISO 12898 standard.

4 Emissivity of real materials

Notion of grey bodies :

If the emissivity of a material does not depend on the wavelength, it is called a grey body. This property does not occur in reality and a body for which the emissivity does not vary in the spectral range studied or useful is called a grey body. A grey body whose spectral properties do not vary with temperature has an emissivity that does not vary with temperature either. Conversely, a surface with a spectral emissivity that varies with wavelength will have a total emissivity that varies with temperature, because the spectral distribution of blackbody radiation varies with temperature.

Reliable bibliographical sources are available. Reference works such as the works of the Thermophysical Properties Research Center of Purdue University (USA), a collection directed by Y.S. Touloukian, can be cited. In particular Thermophysical properties of high temperature solid materials as well as Thermophysical properties of selected aerospace materials part I. The Jet Propulsion Laboratory (JPL) has also published a set of room temperature spectral data of different materials under the name ASTER SPECTRAL LIBRARY.

4.1 Case of dielectrics

The emissivity of a real material usually also depends on the emission angle. For dielectrics, however, the emissivity varies little over a wide angular range (from 0 to 60◦). The *Figure 4***Erreur ! Source du renvoi introuvable.** from [7] shows the total directional emissivity as a function of angle for a number of materials. It can be seen that this does not vary up to an angle of 60◦. Furthermore, the law of variation of emissivity as a function of angle shows a similarity in shape. In this figure has been placed oxidized aluminium and copper, indeed these surfaces behave primarily as a dielectric: their oxides.

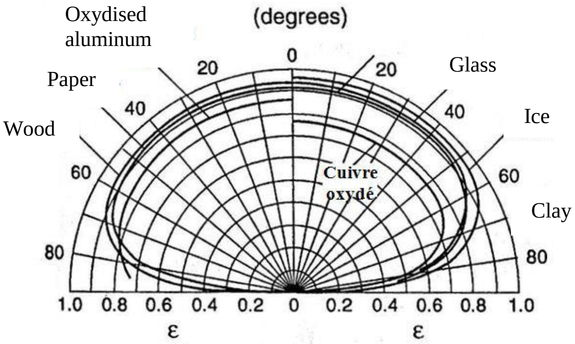

Figure 4 *Total directional emissivity as a function of direction from* **[7]**

4.2 Case of metals

Metals have relatively low emissivities, but the surface condition has a strong influence on this value (roughness, oxidation). In addition, the temperature can have a significant influence on this value. Table 2 shows examples of values that can be found in the literature. These values are of little use to the experimenter given the high variability of the values found.

Table 2 *Emissivity of several metallic surfaces*

Metal	Normal directional emissivity	Metal	Normal directional emissivity
Polished aluminium	0.04 à 0.1	Inconel	0.55 à 0.78
Sandblasted aluminium	0.3 à 0.6	Polished steel	0.2
Oxidised aluminium	0.2	Raw steel	0.45
Anodised aluminium	0.7	Highly oxidised steel	0.95
Bronze	0.1	Polished molybdenum	0.05
Chrome at 300K	0.1	Oxidised molybdenum	0.5 à 0.8
Chrome at 800-11000K	0.28 à 0.38	18/8 stainless steel	0.16
Polished gold	0.02	Stainless steel 18/8 oxidised	0.8

5 The different methods of measuring thermal emissivity

The measurement techniques presented in this document are only applicable to **opaque** materials, i.e. materials that are opaque at a very low thickness, in the order of a micrometre. Calorimetric methods are not presented here as they are not useful for infrared thermography applications (see [8] [9] [10] for calorimetric methods).

Emissivity measurement methods are classified into two categories according to the physical principle of measurement. The so-called direct methods are those where the partial or total radiation radiated by the surface of the material is measured directly. Indirect methods are those where the emissivity is calculated from the result of measuring a reflection factor. Most measuring instruments on the market use an indirect method.

5.1 Direct measurement methods

5.1.1 Measurement of spectral or "broadband" directional emissivity by direct measurement of luminance

This method consists of comparing the luminance of the sample surface with that of a black body heated to the same or a similar temperature. The device is schematically presented by the *Figure 5*. In this figure, the sample A is brought to the desired temperature and placed in a cooled chamber B, the temperature of which is sufficiently different from the surface temperature of the test piece. The black body E is brought to a temperature close to that of the sample and is the reference luminance source. The directional radiation from the black body and the sample is measured successively using the tilting mirror C. The ratio between the two radiometric signals weighted by the luminance ratio taking into account the actual temperatures of the blackbody and the sample surface gives the emissivity (relation 18). Radiation is measured using the D-system. This can be equipped with a broadband sensitive infrared detector (such as a thermopile) to measure the "near total" emissivity. The detection system can also be equipped with filters to measure the spectral directional emissivity for different wavelength bands [11]. The NIST (National Institute of Standards and Technology, Gaithersburg, Maryland, USA) set of blackbody emissivity measurement devices is presented in [12]. In order to measure the emissivity for different directions and to trace the hemispheric emissivity, some devices are equipped with a rotation of the sample: this is the case of the device described in [13]. A monochromator can also be used for spectral selection as described in [14].

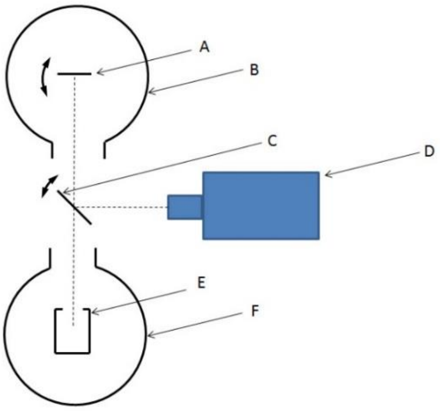

***Figure 5** Diagram of the radiometric method*

The spectral directional emissivity value is obtained from the radiometric signals and measured temperatures using relationship (13) :

$$\varepsilon_\lambda = \frac{S_e - S_o}{S_{CN} - S_o} \cdot \varepsilon_{CN} \cdot \frac{\int_{\lambda_1}^{\lambda_2} K_\lambda \cdot [L(\lambda, T_{CN}) - L(\lambda, T_0)] \cdot d\lambda}{\int_{\lambda_1}^{\lambda_2} K_\lambda \cdot [L(\lambda, T_e) - L(\lambda, T_0)] \cdot d\lambda} \quad (13)$$

where ε_λ is the spectral directional emissivity of the specimen, S_e is the radiometric signal measured on the specimen, S_{CN} is the radiometric signal measured on the blackbody, S_0 is the radiometric signal measured on the shutter at room temperature, λ_1 and λ_2 are the limiting wavelengths of the spectral sensitivity band, K_λ is the spectral sensitivity of the detector, $L(\lambda, T)$ is the spectral luminance at wavelength λ and temperature T, T_{CN} is the temperature of the blackbody, T_0 is the temperature of the shutter and T_e is the surface temperature of the test piece. The relationship applies regardless of the width of the spectral band of measurement, if the spectral band is very wide it is necessary to know the spectral sensitivity of the detector or to be certain that the spectral sensitivity is constant over the entire spectral band. If the detection spectral band is very narrow, the spectral sensitivity can be reasonably assumed to be constant and the relationship becomes :

$$\varepsilon_\lambda = \frac{S_e - S_o}{S_{CN} - S_o} \cdot \varepsilon_{CN} \cdot \frac{[L(\lambda, T_{CN}) - L(\lambda, T_0)]}{[L(\lambda, T_e) - L(\lambda, T_0)]} \quad (14)$$

5.1.2 Periodic radiometric method

The periodic radiometric method consists of modulating the temperature of the sample slightly around the average temperature at which we wish to know the emissivity. It is thus possible to separate the reflected flux from the flux emitted

by the sample. This is the principle of the modulated radiometric method. To obtain the emissivity of any material, the measured flux must be compared with that of a surface of known emissivity.
Another method is to also modulate a hemispherical source at a frequency different from the modulation frequency of the sample. By performing the measurement on two unknown samples, the emissivity and reflectivity values can be obtained. This method does not require an emissivity reference to perform the measurement. The periodic radiometric method is detailed in [20].

5.2 Indirect method by measuring a hemispherical or hemispherical directional reflectance

The reflectometric method consists of measuring the spectral hemispherical directional reflectance $\rho^{\cap|}$ or the spectral hemispherical directional reflectance $\rho^{|\cap}$. The spectral directional emissivity is calculated using relationship 20; the direction for which the emissivity is given is the direction of incidence in case of spectral hemispherical directional reflectance measurement or the direction of measurement of the reflected radiation in case of spectral hemispherical directional reflectance measurement. Relation 15, applicable only for opaque material, is based on relation 6 and Kirchhoff's law.

$$\boldsymbol{\varepsilon(\lambda) = 1 - \rho(\lambda)} \quad (15)$$

5.2.1 Integral sphere measurement method

The sample is illuminated by a directional incident beam of radiation from a direction close to the normal to the surface. The angle of incidence in conventional integrating spheres is between 8° and 12°. The incident beam is partly absorbed by the surface and partly reflected. The inner wall of the sphere has the property of strongly reflecting the radiation and scattering it. This radiation is proportional to the radiation reflected by the specimen. The detector, placed on the side, receives part of the radiation and therefore provides a signal proportional to the radiation reflected by the test piece and to the power of the incident beam. A device of this type is used at NIST. It is described in [15].

5.2.2 Method using a modulated source

Previously, for the radiometric method, when one wished to measure the flux emitted by the surface, it was necessary to free oneself from the flux coming from the radiative environment around the sample. The sample was therefore placed in a chamber cooled to a temperature T_e , so as to ensure $\sigma.T^4 >> \sigma.T_e^4$. This constraining condition is however easy to achieve with a water-cooled chamber for sample temperatures above 1000K (error less than 1%). However, when one wants to measure an emissivity at room temperature, it is necessary to cool the chamber to cryogenic temperatures. To avoid this additional complexity, the temperature of the sample to be measured can be modulated around the temperature at which the emissivity is to be measured [16]. When it is not possible to modulate the temperature of the sample, a reflectometric method can be used and the flux used to measure the reflectance can be modulated [17]. These methods are described in [18] and a specific example is given in [16]. Another method of modulating the hemispherical flux is to use a three dimensional moving screen. This device has been patented by the University of Paris XII [19].

5.3 Summary of the different measurement techniques

For better readability of the different measurement techniques, they have been grouped in the *Figure 6*. This highlights the assumptions required to obtain the total hemispheric emissivity and therefore the sources of uncertainty in these measurements.

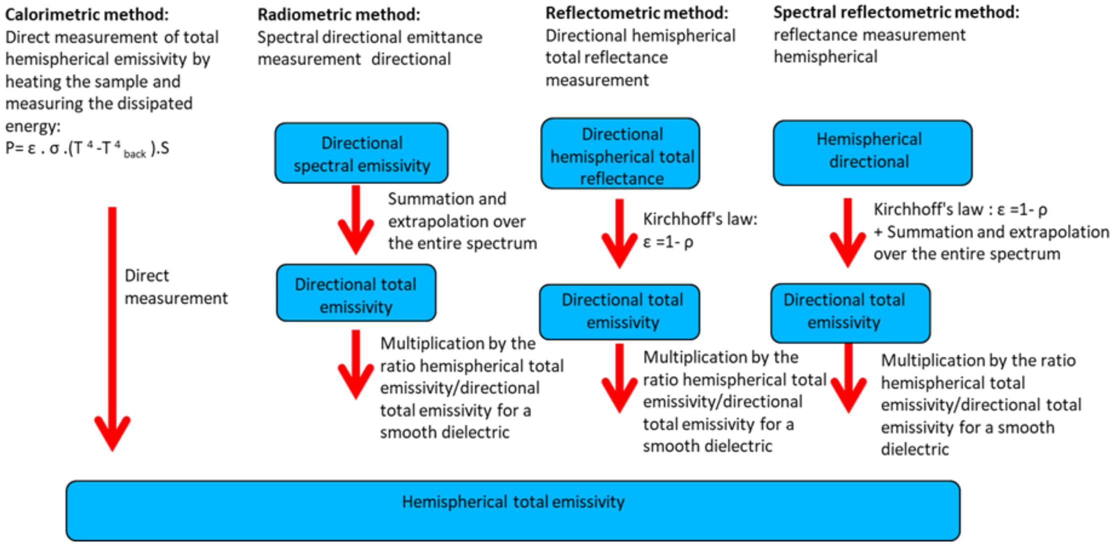

Figure 6 *Summary of the different direct and indirect emissivity measurement methods*

6 Examples of commercial emissivity meters

6.1 Temp 2000 from AZ-technology

This device (*Figure 7*) replaces an earlier device manufactured by Gier and Dunkle [11]. The *Figure 8* shows an extract from the patent (patent number US-5659397). The following description uses the numbers in the diagram legend. The source (56) is chopped by an optical chopper (122), frequently referred to as a chopper. The moving screen is perforated at (124). A mirror (60) focuses the light from the source onto the sample. The sample is placed at the focus of an ellipsoidal mirror (20). The second focus is occupied by the detector (70). Thus, all reflected rays from the sample converge on the detector. As in the integrating sphere, holes can be made to eliminate specular reflection. To perform the calibration, a clever device allows the entire beam from the source to be sent to the detector: a mirror (80) mounted on a drawer (86) can be placed in the beam path to send the entire flux to the detector. If the reflection coefficient of the movable mirror (80) and the ellipsoidal mirror (20) is known, the reflection coefficient of the sample can be deduced.

Figure 7 *Photo of AZ-Technology Temp 2000*

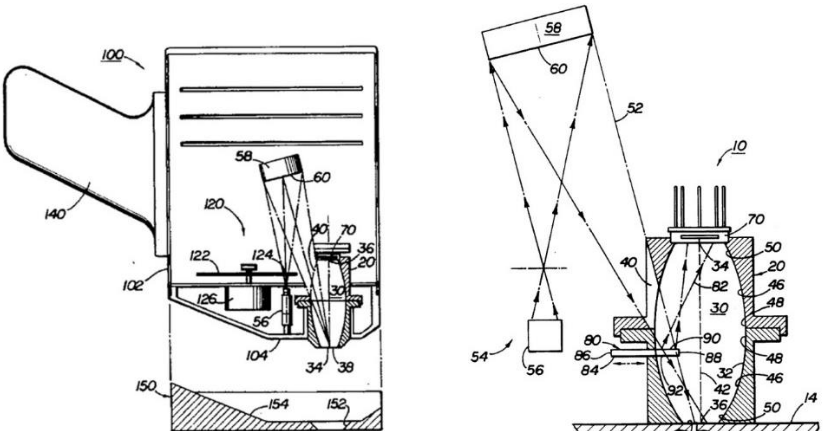

Figure 8 *AZ-Technology patent US-5659397*

6.2 INGLAS TIR100-2 Emissometer

This device works on the principle described in the *Figure 9Figure 9*. It allows the measurement of quasi-normal total directional emissivity. The surface to be characterised is illuminated by a hemispherical infrared source covered with an emissive coating heated to 100 °C. A portion of the reflected radiation is measured using a Fresnel lens that focuses the quasi-normal radiation from the surface reflection onto a thermopile detector. After calibration using two calibrated samples of known emissivity, the emissivity of an unknown surface can be determined. A major disadvantage of the TIR100-2 is that a correct emissivity measurement can only be made if both standards and the sample to be characterised are at the same temperature. It is therefore necessary to expose the samples only for a short time to avoid heating them.

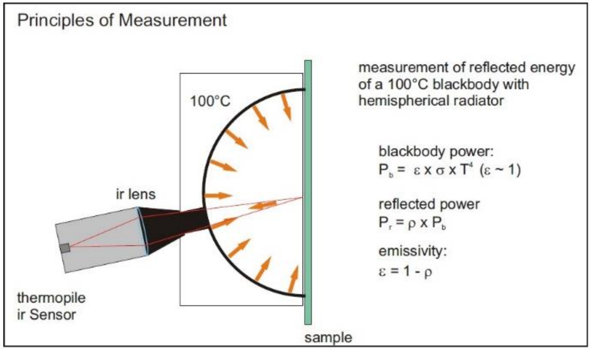

Figure 9 *TIR100-2 Operating principle*

6.3 The ET-100 from Surface Optics

The ET-100 measures directional reflectance at six bands in the thermal infrared spectral region at two incidence angles, 20° and 60°. Based on those values, directional and total hemispherical emissivity is calculated. The ET-100 is a handy tool for radiative heat transfer applications including field inspections.

6.4 Devices and Services Company (D&S) AE Emissometer

This apparatus allows total hemispheric emissivity measurements to be made. The principle consists of placing a heated thermopile covered with a high emissivity surface (*Figure 10*). This apparatus assumes that the emissive surface of the thermopile is grey (Nextel© paint from 3M). A differential heat balance is performed between two elements of different emissivity, one element is covered with a high emissivity coating and the other is covered with a low emissivity coating. The temperature difference between the two elements is measured by a thermopile. For more information, refer to ASTM C1371. A comparative study of emissivity measurements made with this device can be found in [20].

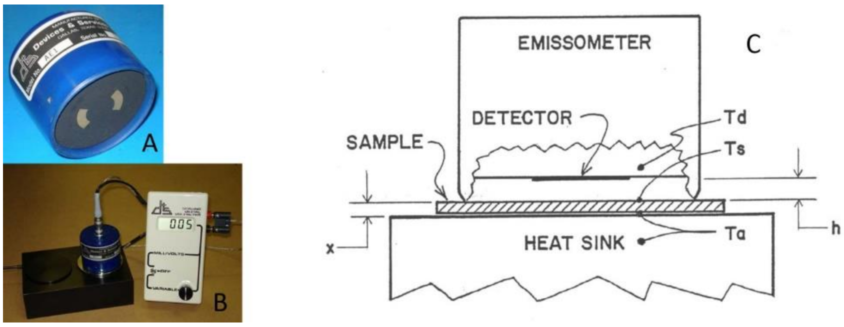

Figure 10 *DEVICES & SERVICES AE Emissivity Meter*

6.5 EM3 from THEMACS Engineering

The principle consists of modulating a hemispherical source with mobile flaps [16] [19] [21]. This avoids modulating the cavity in temperature, which is very slow. The source (*Figure 11*) is the cylinder B heated to a temperature slightly higher than the ambient temperature. The moving cylinder C and the fixed screen D occlude the hemispherical source at a frequency of 10Hz for the cylindrical wall (presence of 6 windows) and 5Hz for the top part (presence of 3 windows). In this way, it is possible to differentiate a specular material from a scattering material. One thermopile measures the incident flux and another the reflected flux. The ratio of the reflected flux does not depend on the level emitted by the source. This emissivity meter must be calibrated beforehand with two known emissivity surfaces. The *Figure 11* shows the general schematic (1), a detail of the movable and fixed shutters, and the source covered with Nextel (3M™) paint (2), an exploded view of the device (3) and a photo of the device. The device is portable.

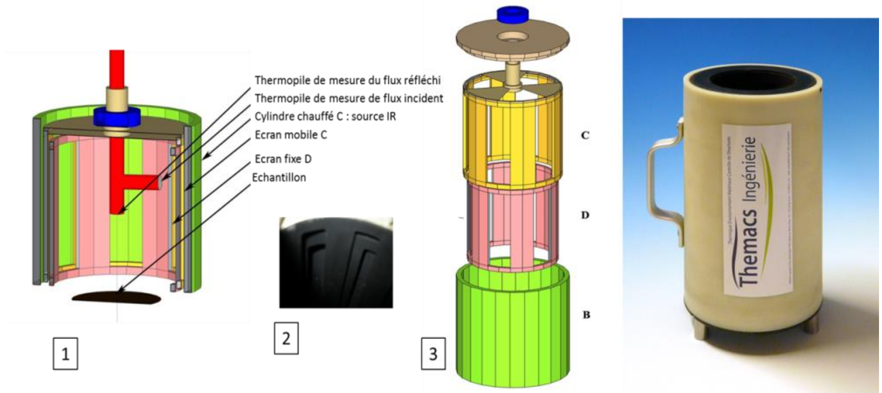

Figure 11 *EM3 Emissometer from THEMACS Ingénierie*

7 Normative texts for emissivity measurements

7.1 Standard NF-EN 12898: Glass in building, determination of emissivity

This European standard specifies a procedure for determining the emissivity of glazing at room temperature. This measurement has become essential for determining the thermal transmittance of windows. The procedure is based on spectrophotometric measurements of reflectance. Unlike the method described in 5.2.1 which uses an integrating sphere, this method consists of measuring the specular reflection at near-normal incidence for 30 specific wavelengths. The total hemispherical reflectance is calculated by averaging the 30 measured values and the total hemispherical emissivity is obtained from the coefficient of Table 1.

7.2 ASTM E408: Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques

This standard describes two types of rapid emissivity measurement methods for large surfaces. These methods are particularly useful for production inspections. The first method is a reflectometric method in which the surface to be examined is illuminated alternately by two half-cylinders heated to different temperatures. The reflected flux is measured using a thermopile. It is therefore a modulated reflectometric method. ASTM E408 is a test method for determining normal directional total emissivity using a handheld device.

7.3 ASTM C835 standard Test Method for Total Hemispherical Emittance of Surfaces up to 1400 ◦C

This method describes a calorimetric method for the determination of total hemispherical emittance up to 1400 ◦C. The materials concerned are metals, graphite and coated metals. The maximum temperature is limited only by the nature of the sample (melting temperature, saturation vapour pressure,...). The principle is to electrically heat a strip of the material to be studied in a vacuum chamber. In the central part of the strip, the electrical power is measured electrically and is equal to the radiated power. Thanks to the Stefan-Boltzmann equation, the emissivity can be deduced. The metal strip is heated by a current. The central measurement area is delimited by the two voltage measurements and must have a uniform temperature. The emissivity is calculated according to the following relationship:

$$U \cdot I = \epsilon \cdot \sigma \cdot T^4 \cdot S \quad (16)$$

where S is the area of the measurement area including the strip edge (S = 2 × (Width+Thickness) × Length).
The best reported uncertainty level for this method is 5%.

7.4 ASTM C1371 Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers

This method should only be used on surfaces covering a highly thermally conductive material. The principle consists of placing two heated elements with very different emissivities opposite the surface to be studied. To obtain the emissivity, the difference in the fluxes exchanged by the two elements is measured indirectly, and the emissivity of the surface measured after calibration is deduced. This is the method used by the commercial AE-AD1 device from Devices and Services described in §2.5.3.

7.5 ASTM E307 Standard Test Method for Normal Spectral Emittance at Elevated Temperatures

This method is a "high precision" measurement method for measuring the directional spectral emissivity for conductive materials or materials with a conductive substrate in the temperature range of 600 to 1400K and for wavelengths from 1 to 35µm. The principle is to compare the luminance of the surface under study with that of the black body at the same temperature. This is the method described in 5.1.1.

8 To go further

There are several general documents that can complement this discussion of emissivity measurements. These include
- Measurement of Thermal Radiation Properties of Solids", [22]. This document is the proceedings of a 1962 conference on the radiative properties of materials.
- Measurement Techniques for Thermal Radiation Properties", [23]. Similarly, this document reviews the state of the art in 1990. New devices are described.

Spacecraft Thermal Control Coatings References [1]. This NASA reference document is one of the most recent and describes the measured quantities.

9 Conclusion

The main emissivity measurement techniques described correspond to existing experimental devices. The great diversity of methods can be seen. This great diversity responds to the need to adapt the devices to the type of parameter desired (directional, hemispherical, total, spectral emissivity, etc.), to the nature of the material, to the configuration of the sample and to the temperature range. There is no universal device for emissivity measurements and currently all commercial devices meet only a small part of the needs. They are largely limited to measurements at room temperature. The most commonly used routine methods are indirect methods (reflectometers) using the measurement of the reflectance to derive the quasi-normal emissivity. These methods are comparative methods and require calibrated samples. Measurements at high and cryogenic temperatures are often the domain of specialised laboratories such as certain National Metrology Institutes. The three leading laboratories in this field in Europe are the Laboratoire National de Métrologie et d'Essai (LNE, France), the Physikalisch-Technische Bundesanstalt (PTB, Germany) and the National Physical Laboratory (NPL, UK). Emissivity measurement remains a difficult measurement and cannot be improvised. It requires a great deal of technical expertise and generally a specific device for each case of study.

10 References

[1]. **Kauder, L.** *Spacecraft Thermal Control Coatings References, NASA-TP-2005-212792,.* 2005.

[2]. **P. Lorrain, D.R. Corson.** *Champs et ondes électromagnétiques.* s.l. : Armand Collin.

[3]. **Rubin, M., Arasteh, D. et Hartmann, J.** *A correlation between normal and hemispherical emissivity of low emissivity coatings on glass.* s.l. : Int. Comm. Heat Mass Transfer, 1987.

[4]. **Blain, B. J. et Douglas, R. W.** *Infra-red optical constants of glasses.* 1965.

[5]. **D. Janssen, J. Lohrengel.** *investigation and development of a method for the measurement of the emissivity of glass.* s.l. : BCR european community, 1991. EUR 13487 EN.

[6]. **GEOTTI-BIANCHINI, F.** *Total hemispherical emissivity of coated glass.* s.l. : European community, 1993. EUR 14758 EN.

[7]. **Maldague, X.P.** *Theory and practice of infrared technology for non destructive testing,.* s.l. : Ed. Wiley, 2001.

[8]. **J. Hameury, B. Hay, J. R. Filtz.** *Measurement of Total Hemispherical Emissivity Using.* s.l. : Int. J. Thermophys, 1607, 2007.

[9]. **C. Fabron, A. Meurat.** *Measurement of total hemispheric emissivity at low temperature.* s.l. : International Symposium on nvironnemental Testing for Space Program, Liège, Belgium, 2001.

[10]. **D. Giulietti, A. Gozzini, M. Lucchesi, R. Stampacchia.** A calorimetric technique for measuring total emissivity of solid materials and coatings at low temperatures. *Journal of Physics D: Applied Physics,.* 1979, Vol. 12, 12.

[11]. **Mazikowski A., Chrzanowski K.** *Non-contact multiband method for emissivity measurement.* s.l. : Infrared Phys. Technol., 91, 2003.

[12]. **L. Hanssen, S. Mekhontsev, V. Khromchenko.** *Infrared Spectral Emissivity Characterization Facility at NIST,* . s.l. : Thermosense XXVI, edited by Douglas D. Burleigh, K. Elliott Cramer,G. Raymond Peacock,Proc. of SPIE Vol. 5405, SPIE, Bellingham,WA, 2004.

[13]. **L. Del Campo, R.B. Perez-Saez, X. Esquisabel, I. Fernandez, M.J. Tello.** *New experimental device for infrared spectral directional emissivity measurements in a controlled environment.* s.l. : Review Of Scientific Instruments, vol. 77, 113111, 1-8, 2006.

[14]. **V. Vitkovskii, V. G. Gorshenev, Y. F. Potapov.** *Measurement of Spectral Directional Emissivity of Materials and Coatings in the Infrared Region of Spectrum.* s.l. : Thermal Engineer , 245-248 Vol. 56-3, 2009.

[15]. **L.M. Hanssen, S. Kaplan.** *Infrared diffuse reflectance instrumentation and standards at NIST.* s.l. : Anal. Chim. Acta, 289 , 1999.

[16]. **L. Ibos, M. Marchetti, A. Boudenne, S. Datcu, J.Livet, Y. Candau.** *Infrared emissivity measurement device : Principle and applications.* s.l. : Meas. Sc. Tech., 2950, 2006.

[17]. **D. Especel, S. Matteï.** *Total Emissivity Measurement Without Use of an Absolute Reference.* s.l. : Infrared Phys. Technol., 777-784 vol.37, 1996.

[18]. **M.Siroux.** *Développement de techniques de mesure de l'émissivité de matériaux opaques à température ambiante. Approches radiométrique et calorimétrique en régime périodique.* s.l. : Thèse Université Paris 12, 1996.

[19]. **Ibos L., Monchau J-P. et Candau Y.** *Dispositif de mesure de l'émissivité ou de la réflectivité d'un échantillon.* s.l. : Brevet N° FR-1251476, 2012.

[20]. **Nelson K.E., Leudke E.E., Bevans J.T.** *A device for rapid measurement of total emitemittance,.* s.l. : Journal of Spacecraft and Rockets, 758-760 ,Vol.3, No. 5, 1966.

[21]. **Monchau J-P., Marchetti M., Ibos L., Dumoulin J.,Feuillet V.,Candau Y.,.** *Infrared Emissivity Measurements of Building and Civil Engineering Materials : A New Device for Measuring Emissivity.* s.l. : Int. J. Thermophys., 2013.

[22]. **NASA.** *Measurement of thermal radiation properties of solids* . s.l. : Symposium held atDayton, Ohio, 1963.

[23]. **Sacadura, J.F.** *, Measurement techniques for thermal radiation properties, Proceedings of The Ninth International Heat Transfer Conference, Jerusalem, Israel P 207-222* . 1990.