Emissivity: Definition and Influence in Non-contact Temperature Measurement

by Albert Book

In non-contact temperature measurement, a pyrometer detects the thermal energy or infrared radiation emitted by an object. from this detected radiation, the pyrometer calculates the temperature according to Planck's radiation law. The amount of energy emitted by the object largely depends on the emissivity of the material.

But what exactly do we mean when we refer to emissivity, and how will it influence the temperature measurement? How can we determine the amount of emissivity, and what does it depend on? What kind of temperature reading errors might occur due to an incorrect emissivity setting and how can one prevent measuring errors? This article discusses these and other questions about emissivity.

Definition of emissivity

The amount of infrared/thermal energy an object will radiate is not only a function of temperature, but depends on the material itself. Emissivity describes a material's ability to emit or release the thermal energy which it has absorbed. A perfect radiator – known as a 'black body' – will emit the entire amount of absorbed energy. A real body will always emit less energy than a black body at the same temperature. Emissivity ε is the ratio of infrared radiation emitted of a given object (real body) Φr and a black body Φb at the same temperature.

$$\varepsilon = \Phi r / \Phi b$$

Thus, emissivity is a nondimensional quantity or factor between 0 and 1, or between 0 and 100%.

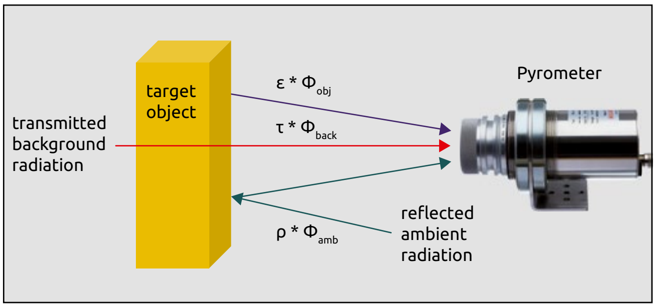

Fig. 1 *Composition of radiation received by the pyrometer's sensor.*

Atmospheric radiation which reaches a measurement object is reflected more or less strong, depending on the material's reflectivity. The same laws of radiation which govern visible light also apply to thermal energy. In the case of transparent objects such as glass or plastic foil, additional thermal energy from below the object's surface or from the background might contribute to the radiation detected. Transmissivity describes the percentage of radiation which can be transmitted through an object. The total amount of radiation detected by a pyrometer's sensor Φ_Σ is the sum of several components, as shown in the following equation.

$$\Phi_\Sigma = \varepsilon * \Phi_{obj} + \rho * \Phi_{amb} + \tau * \Phi_{back}$$

ε = Emissivity factor
ρ = Reflectivity factor
τ = Transmissivity factor
Φ_{obj} = Radiation from target object
Φ_{amb} = Ambient radiation (foreground)
Φ_{back} = Radiation from background

The radiation coefficients are linked together in the equation:

$$1 = \varepsilon + \rho + \tau$$

There will be no transmission of radiation through opaque objects; thus the transmissivity factor will not be applicable.

$$1 = \varepsilon + \rho$$

Factors which influence emissivity

The emissivity of an object depends primarily on the type of material and its surface properties. Nonmetallic and nontransparent objects are generally good radiators with an emissivity > 80 %. The emissivity of metals can vary between 5% and 90 %. Shiny, highly reflective metal surfaces will have lower emissivities.

Furthermore, the emissivity can change depending on the wavelength. This is especially true for metals. The ability of a metal to emit thermal radiation increases at shorter wavelengths. Therefore, for metal applications, it is best to select a pyrometer which measures at short wavelengths.

Transparent objects such as glass, plastic films, or gases have distinct wavelength ranges in which the radiation characteristics are good. In order to accurately measure the temperature of these objects, it is necessary to select pyrometers with special sensors and filters which are sensitive to the particular wavelength.

The emissivity of metals and glass also changes as a function of temperature. Through surface oxidation of liquid metal and during the liquid to solid transition the emissivity can change considerably.

Material	Wavelength
glass	4,8 μm
plastic films made of PE, PP, PS	3,43 μm
plastic films made of PET, PA, PUR	7,9 μm
cold flue gases	4,27 μm
hot flue gases	4,5 μm

As the temperature of a metal increases, so will the emissivity. In the case of glass, a higher temperature allows the pyrometer to see at a greater distance into the glass. This means that the pyrometer will measure at a depth below the glass surface, detecting thermal energy from within the object.

How atmosphere influences emissivity

Extraneous radiation can arise in environments in which measurements take place. A classic example is the measurement of cold sheet metal within a hot heating furnace. The pyrometer detects both the thermal energy which radiates directly from the sheet metal as well as the thermal radiation from the furnace wall which reflects off the sheet metal. The smaller the temperature difference between the two sources of radiation (object and furnace), the greater the accuracy of the measurement.

To detect the actual temperature of the object a water-cooled sighting tube should be employed. This accessory serves to shield the pyrometer from interfering radiation from the furnace wall. In order to block the reflected radiation from entering the sight path, the tube diameter should measure at least six times the distance between the tube and the object.

Ways to determine emissivity

Industrial literature or instruction manuals often contain data on the emissivities of various materials. This information should be used with caution, however. It is important to know for which temperature and which wavelength the emissivity value is applicable. Furthermore, the stated emissivity values were obtained under ideal conditions. In actual practice, the total emissivity of the target object will vary, depending on the amount of extraneous radiation transmitted through the object from the background or reflected onto the object from the foreground. If you were to adjust the pyrometer for the theoretical emissivity value drawn from literature, the displayed temperature reading will be erroneously high.

To obtain an accurate temperature reading, the user will have to adjust the pyrometer for a somewhat higher emissivity than declared. We could call this a simulated increase in emissivity. Through a comparison measurement using a contact thermometer we can establish the actual emissivity of an object and adjust the pyrometer accordingly, provided that the contact thermometer measurement is very precise.

Alternatively, for temperatures up to approximately 250 °C, a sticker with a defined emissivity can be affixed to the target object.

First, the true object temperature is determined at the sticker spot (**Fig. 2**). Then a comparison measurement is performed at the object right next to the sticker. Subsequently, the pyrometer's emissivity is adjusted so that the instrument displays the prior temperature reading. Because the influence of

Fig. 2 *Determine emissivity by comparison measurement on emission adhesive tape with defined emissivity.*

Fig. 3 *Intensity comparison pyrometer PV 11 for precise visual temperature measurement.*

emissivity tends to increase with temperature, this comparison measurement should always be performed at higher temperatures

When measuring high temperatures or if the target is difficult to access, such as in a vacuum furnace, a comparison measurement using a pyrometer for short wavelengths is recommendable, because for reasons of physics, the accuracy of the measurement will be greater at shorter wavelengths.

A disappearing modern intensity comparison pyrometer (**Fig. 3**) is ideal for this purpose. The technique of this instru-

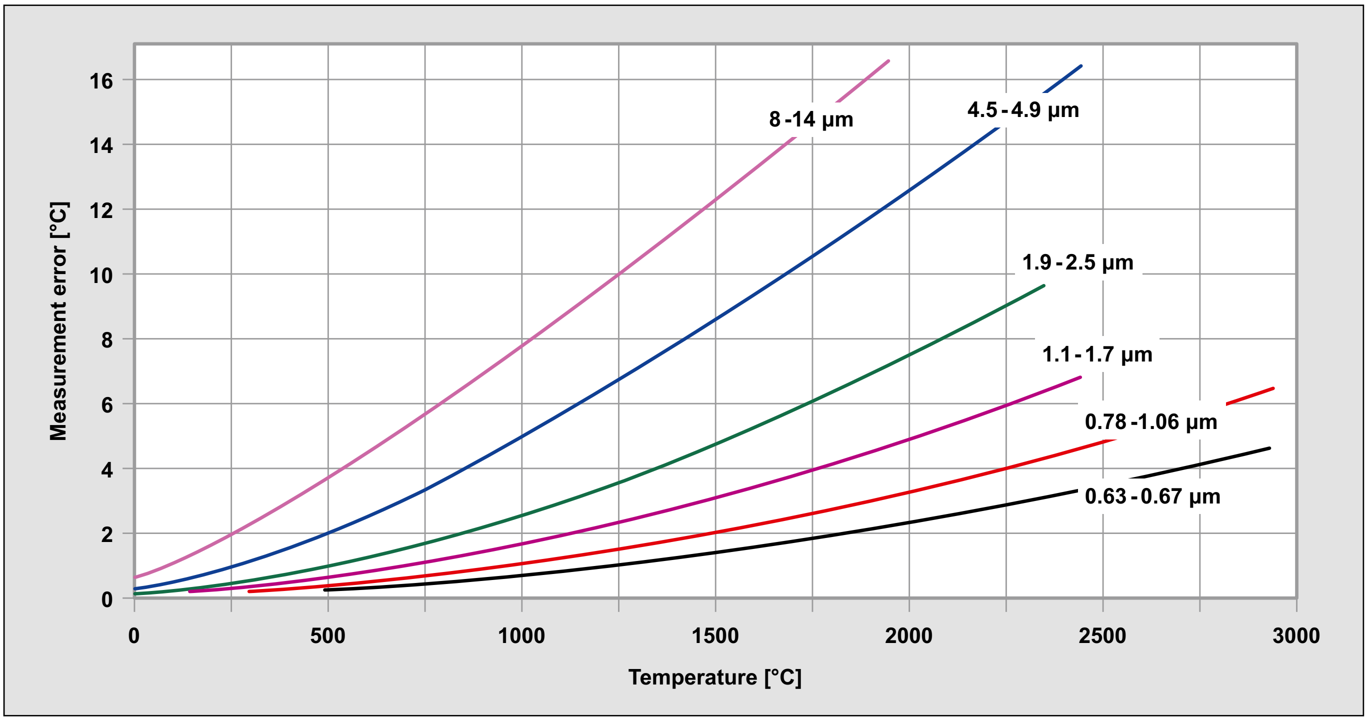

Fig. 4 *At 1% change in emissivity, depending on temperature and wavelength.*

ments is based on a visual colour comparison at a wavelength of 0.67 μm.

This method's effectiveness is not dependent on the size of the target object. The chart **Fig. 4** demonstrates the effect of an incorrect pyrometer adjustment or a change in emissivity.

Two-colour pyrometers measurements – irrespective of emissivity?

Several years ago, pyrometers which had the ability to simultaneously detect thermal radiation at two different wavelengths came out on the market. The ratio of these two measurements is proportional to temperature. If the emissivity of the target material changes and effects a change in the amount of radiation detected by each channel, the ratio or quotient of these values, and thus the temperature, will still remain constant. This is only true, however, when the change in emissivity is identical for both channels. Practice has shown that this is rarely the case for metals. For metal applications, the use of two-colour pyrometers can result in even greater measuring errors than a one-channel pyrometer would produce. Therefore, caution is advised with this often cited "emissivity-independent" technique.

Two-colour pyrometers do offer clear advantages in situations which produce the same degree of signal attenuation at both channels, for instance when dust or smoke on the lens or in the instrument's field of view partially obstruct the transmission of radiated energy to the pyrometer sensor. The temperature reading of the two-colour pyrometer will continue to be correct.

In particularly unfavourable or complex measuring conditions, it is recommendable to consider both the two spectral temperature values as well as the temperature reading based on the two-colour ratio. Depending on the result, the user can select the method which is best suited for his application and adjust the pyrometer accordingly.

Conclusion

When pointing out the attributes of a pyrometer, brochures often draw special attention to an instrument's specified measurement uncertainty. With non-contact temperature detection, however, the likelihood of measurement errors occurring will depend for the most part on target object characteristics and ambient conditions. Only rarely do metrological errors actually stem from a flawed instrument. Therefore, whether selecting a pyrometer or choosing the measuring position, it is best to keep in mind the principles described in this article.

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