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# Limit of the Bichromatic Pyrometer for Determining the Temperature of a Metal

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**ABSTRACT:** The limitations of infrared thermometers used during metal heat treatment will be explored at the end of this article. Thanks to the infrared detector, and one of the physical properties of hot metals, which is the ability to radiate, the temperature on the surface of the target object can be remotely measured. This temperature is proportional to the emitted infrared radiation. The system is equipped with optical filters to control the infrared radiation and focus it on the detector. The light energy received by the detectors is directly transformed into electrical energy, which can be processed electronically.

**KEYWORDS:** Pyrometer, detector, infrared radiation, temperature, wavelength, metals.

## I. INTRODUCTION

Temperature is a vital physical quantity in manufacturing. Most often, contact sensors are used to determine it, but this technique is not applicable to moving objects, objects located in hazardous areas, objects with poor thermal conductivity, deformable surfaces, and especially objects with very high temperatures. The metallurgical industries are the most affected by these problems in the heat treatment of metals. But what are the limits of this system?

In this article, we will outline the limitations of this infrared thermometry system adapted to the metallurgical industry.

## II. CONCEPT OF HEAT AND TEMPERATURE

Heat is a form of energy exchanged between two bodies. When a body receives heat, the agitation of its molecules intensifies, which most often results in an increase in its temperature, which is a measurable physical quantity. This energy exchange occurs in three ways:

- Conduction heat transfer involves the propagation of heat from molecule to molecule.
- Convection heat transfer is characterized by the propagation of heat in a moving gaseous or liquid guide.
- Radiation heat transfer is a phenomenon caused by an exchange of electromagnetic energy, without the intermediate environment does not participate in this exchange.

## III. INFRARED RADIATION

All bodies with a temperature above 0°K are capable of emitting energy in the form of radiation at their surface and exchanging it with each other. The amount of energy emitted is related to the temperature at the body's surface. Therefore, it is possible to measure the temperature of a hot body by using its emitted radiation.

The atoms and molecules of a hot solid are arrangements of oscillating electrical charges, and all oscillating charges emit electromagnetic radiation. The intensity of the emitted radiation depends on the intensity of the oscillation, which is why a heated solid emits more radiation than the same solid at a lower temperature.



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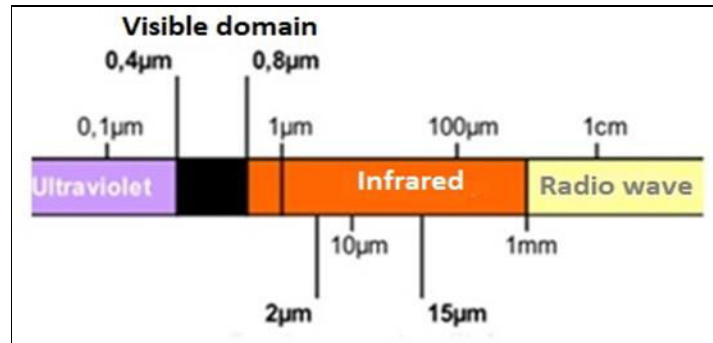


Fig. 1 Different infrared ranges

The infrared spectral band extends from 0.8 to 1000  $\mu\text{m}$ . This band is divided into three parts: near, mid, and far. The spectral band used in infrared thermography is between 2  $\mu\text{m}$  and 15  $\mu\text{m}$ , but for measuring high temperatures during heat treatment, the near-infrared region is used.

#### IV. RADIATION OF BLACK BODY

A black body is a body that absorbs all the energy it receives and re-emits it in the form of radiation. This phenomenon is characterized by:

1. Planck's relation which gives the luminance of the black body as a function of the object's temperature has the following expression:

$$L_{\lambda}^0(T) = \frac{2hc^2}{\lambda^5 e^{\left(\frac{hc}{k\lambda T}\right)} - 1}$$

2. For the law of Stefan-Boltzmann, the calculation gives, after integration of Planck's formula on wavelength  $\lambda$ , the total emittance, that is to say the total power radiated in the upper half-space per unit area of the black body.

$$M^0 = \int_0^{\infty} M_{(\lambda,T)}^0 d\lambda$$

After the integration:  $M^0 = \sigma_s T^4$ ,

With  $\sigma_s$  is the Stefan-Boltzmann constant which is  $5.67 \cdot 10^{-12} \text{ W cm}^{-2}\text{K}^{-4}$

If  $\lambda < 5 \mu\text{m}$  (visible and near infrared), the energy of a photon is much higher than the thermal energy, the Planck relation can be approximated by the Wien relation.

$$L_{\lambda}^0(T) = C_1 \lambda^{-5} \exp\left(-\frac{C_2}{\lambda T}\right)$$

#### V. RADIATION OF OTHER BODY

Real bodies reflect or diffuse part of the incident radiation and emit a flux that is always lower than that of a black body, regardless of temperature or wavelength. But gray bodies are bodies whose emissivity does not vary with wavelength. However, for selective bodies, emissivity varies with wavelength. It is the ratio between the monochromatic luminance of the real source and that of the black body.

$$\varepsilon_{\lambda} = \frac{L_{\lambda}(T)}{L_{\lambda}^0(T)}$$

In general, it depends on the source, wavelength, temperature, and direction of emission. If luminances are replaced by emittances, emissivity became the hemispherical spectral emissivity  $\varepsilon_{\lambda}^*$ .

$$\varepsilon_{\lambda}^* = \frac{M_{\lambda}(T)}{M_{\lambda}^0(T)}$$

It depends only on the source, wavelength, and temperature. And total emissivity is similarly defined by the following relationship:



$$\varepsilon_i = \int_0^\infty \varepsilon_\lambda d\lambda \text{ and } \varepsilon_i^* = \int_0^\infty \varepsilon_\lambda^* d\lambda$$

The luminance of the black body does not depend on the direction of emission, and if the same is true for the real source (source radiating according to Lambert's law), the spectral emissivity does not depend on the direction of emission either.

$$\varepsilon_\lambda = \varepsilon_\lambda^* \text{ et } \varepsilon_i = \varepsilon_i^*$$

### VI. BICHROMATIC PYROMETERS

In the fig. 2, the thermal radiation emitted by the target object is focused by using an optical system that selects the desired spectra on a detection element. The signal obtained will be passed to electronic processing and finished by displaying the results.

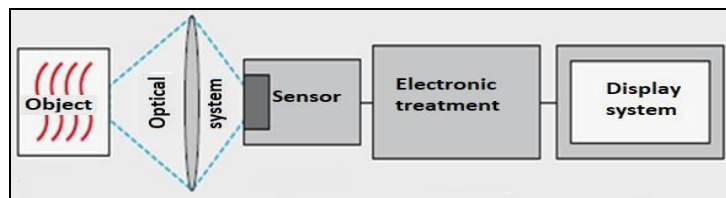


Fig. 2 Infrared measuring system base

In the fig. 3, the radiation from the source is filtered by optical systems which allow two different spectra to pass through and converge them respectively towards the two identical detection systems.

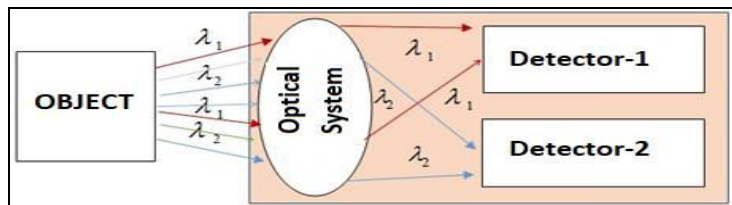


Fig. 3 General principle of bichromatic pyrometers

### VII. RESULT AND DISCUSSION

As metals often reflect radiation, they are generally characterized by a low degree of emission, which is highly dependent on the surface structure and tends towards to long wavelengths. The choice of detection technique depends entirely on the following criteria:

1. Influences of the ambient environment

In the fig. 4, thermal radiation sources located near the target object represent an additional influencing factor.

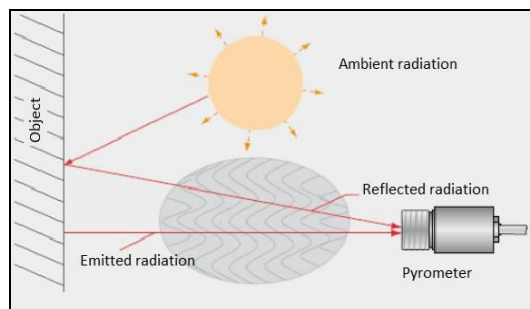


Fig. 4 Ambient environment



|| Volume 14, Issue 10, October 2025 ||

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To prevent distortion of measurement values due to high ambient temperatures, the influence of this radiation must be compensated.

Dust, smoke, and particles suspended in the atmosphere can foul the optics and also lead to inaccurate measurement results. The use of blowers prevents particles from settling in front of the optics. Accessories for air and water cooling allow the use of infrared thermometers in harsh ambient conditions.

### 2. Obstacle during treatment of metal

The presence of obstacles, such as smoke or ash in the furnace, poses problems for temperature measurement. Compensating for ambient radiation is very difficult, as is determining emissivity. Given these facts, bichromatic pyrometer could not give the exact result.

### 3. Choice of two wavelengths

In the fig. 5, the emissivity of metals becomes low as their wavelength increases. Therefore, the error in measuring the temperature increases with the wavelength. And to have a high emissivity of the metal surface, the capture of short wavelength radiation is reliable, that is, near infrared or visible wave. So low temperature measurement of metals for this technique is not recommended.

In addition, the sensitivity of the bichromatic pyrometer will be greater as the difference between the two wavelengths becomes smaller. But the precision of the color temperature measurement will be getting into worse.

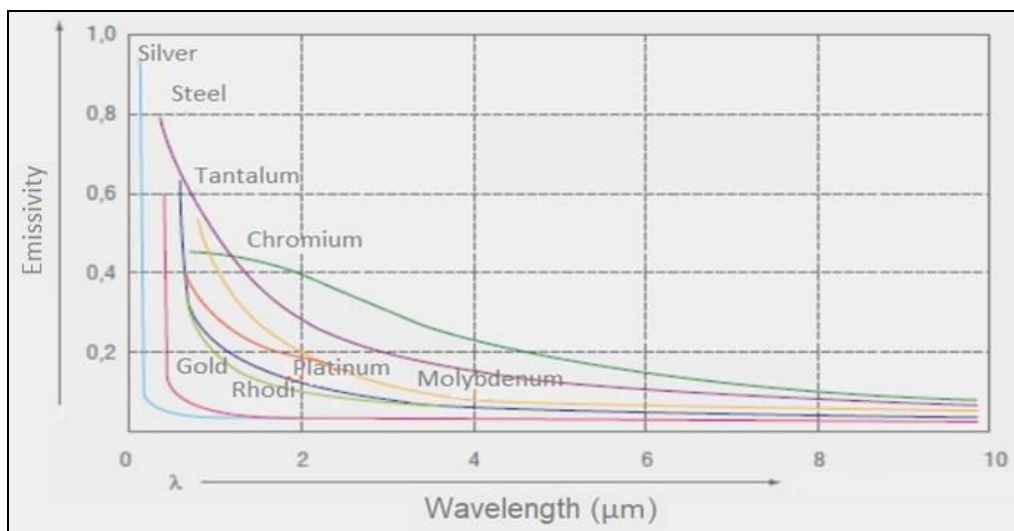


Fig. 5 Spectrum emission degree of metal as the wavelength

In the fig. 6, air is not at all permeable in all infrared regions. Its permeability is found only in a few segments of the infrared spectrum, i.e. between 1.1 and 1.7 μm, 2 and 2.5 μm, and 3 and 5 μm. Therefore, it is better to use the spectrum between 0.8 μm and 1.7 μm. Due to this little range, just the germanium detector technology only which is the most sensitive. We cannot use the other technologies.

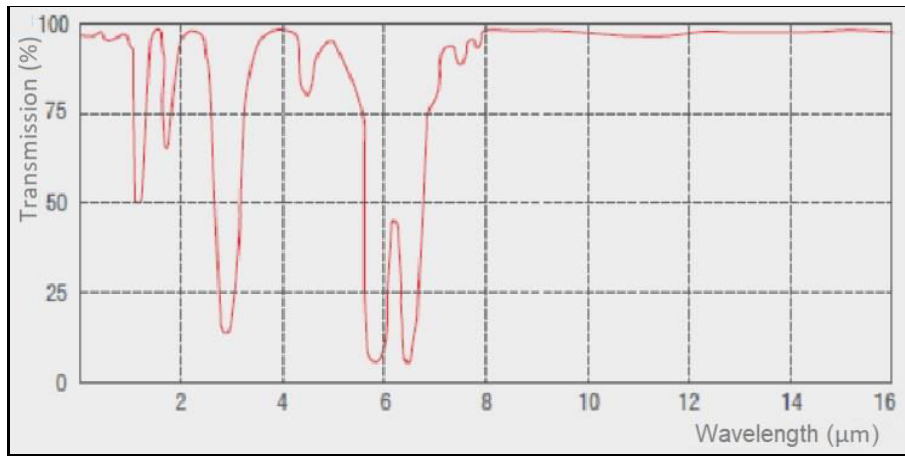


Fig. 6 Spectral permittivity of air

4. Choice of components

Seen that the chosen wavelengths are around 1 μm, so it is better to use a germanium photodiode only. Infrared radiation is low-energy, therefore using a photovoltaic system must apply instead of photoconductor mode for the preamplifier.

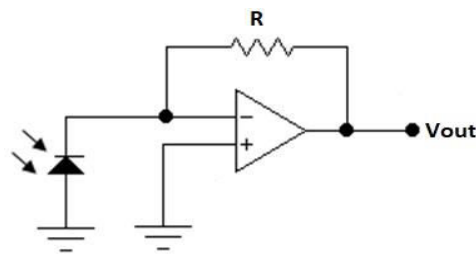


Fig. Fehler! Kein Text mit angegebener Formatvorlage im Dokument. Basic assembly in photovoltaic mode

$$V_s = -\alpha R \phi$$

Where  $\phi$  is the luminous flux and sensitivity of the photodiode

The value of the resistor R depends on the extent of the sensitive surface of the photodiode.

5. Calculation of temperature

The signal delivered by one detector is given by the relation:

$$E(\lambda, T) \approx C \varepsilon_\lambda L_\lambda^0(T)$$

With  $E(\lambda, T)$  is the detector signal.

C is device-specific constant

Since the wavelengths used are close to 1μm and therefore the Wien approximation is applicable, the expression for monochromatic luminance then becomes:

$$L_\lambda^0(T) = CC_1 \lambda^{-5} \exp\left(-\frac{C_2}{\lambda T}\right)$$

Now our device has two detection heads, so we have a system of equations with three unknowns. These are the temperature and the two spectral emissivities.

$$\begin{cases} E(\lambda_1, T) = C \varepsilon_{\lambda_1} L_{\lambda_1}^0(T) \\ E(\lambda_2, T) = C \varepsilon_{\lambda_2} L_{\lambda_2}^0(T) \end{cases}$$

If we consider that metals are generally gray, then the two emissivities are equal, that is to say the emissivity does not vary with the wavelength.

$$\varepsilon_{\lambda_1} = \varepsilon_{\lambda_2} = \varepsilon$$



The previous system of equations then becomes:

$$\begin{cases} E(\lambda_1, T) = C\varepsilon L_{\lambda_1}^0(T) \\ E(\lambda_2, T) = C\varepsilon L_{\lambda_2}^0(T) \end{cases}$$

But all metals are not gray, that is to say selective,  $\varepsilon_{\lambda_1} \neq \varepsilon_{\lambda_2}$ . So, we get a system of equations with two equations and three variables, temperature and the two spectral emissivities. The resolution will be complicated.

### VIII. CONCLUSION

Measuring the temperature of metals, given their natural characteristics, requires a very special measurement system. Measuring using two different colors is the most effective technique for overcoming obstacles.

But the bichromatic pyrometer is only applicable to non-oxidized metals. The wavelength range is very narrow in the infrared region, which is between 0.8  $\mu\text{m}$  and 1.7  $\mu\text{m}$ . However, in this range, the emissivities of metals are almost low, so the measurement error increases. This method cannot therefore be used for low-temperature detection. Compensating for ambient radiation is very complicated. In addition, not all metals are perfectly gray, i.e., selective; knowledge of the emissivity will be necessary to determine the exact surface temperature. Calculating the temperature becomes very difficult. The detector can only be selected from a germanium photodiode detector in the wavelength range with a photovoltaic mode for the preamplifier. The higher the spectral sensitivity of the bichromatic pyrometer, the precision became lower.

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