Measurement of the normal spectral absorptivity of liquid metal at the wavelength of the heating laser through infrared pyrometry

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Extended abstract

The development of a three-colour pyrometer dedicated to the measurement of the normal spectral absorptivity of liquid metal at the wavelength of the heating laser is presented here. Through Kirchhoff's law, the absorptivity at a given wavelength can be deduced from normal spectral emissivity. The absorptivity is a key parameter when a sample is heated by a laser in order to compute the absorbed part of the laser power. This study deals with a 1 070 nm ytterbium fiber laser. The normal spectral absorptivity is measured as a function of temperature above the melting point of liquid metals. Although direct absorptivity measurements at the laser wavelength can be performed for liquid metals, such measurements cannot be carried out while the laser is operating, since the signals received by the instrumentations associated to the experiment would be disturbed and saturated. Therefore, the signal is treated during cooling, when the laser is switched off. However, measuring the absorptivity implies to know the temperature according to Planck's law. For this reason, a three-colour pyrometer is developed.

Among the three wavelengths, the central one, λ_2, corresponds to the one of the laser (1 070 nm). Signals from the two other wavelengths, λ_1 and λ_3, are used to evaluate the temperature. The wavelengths chosen are respectively 950 nm and 1 250 nm. This pyrometer is used during aerodynamic levitation of spherical liquid samples (2 mm diameter) heated by a laser. This apparatus has been developed for the characterization of physical properties (density [1], surface tension [2], heat capacity [3], and viscosity [4]). The three-colour pyrometer is composed of two converging lenses that focus on an area of 2 mm of diameter and collect radiative flux (Figure 1). This radiative flux passes through an optical fibre and another converging lens and is split by two dichroic mirrors to three Gaussian pass-band filters and silicon sensors. Dichroic mirrors are oriented at 45° and reflect and transmit parts of the radiative flux, respectively, inferior and superior to cutting wavelengths of 1 000 nm and 1 150 nm. In this study, three metals are tested: nickel (purity 99.99 %), pure iron (purity 99.95 %) and pure zirconium (purity 99.20 %). The sample is heated by the laser above the melting temperature, then the laser is switched off and the sample cools. Before solidification, it reaches a supercool state.

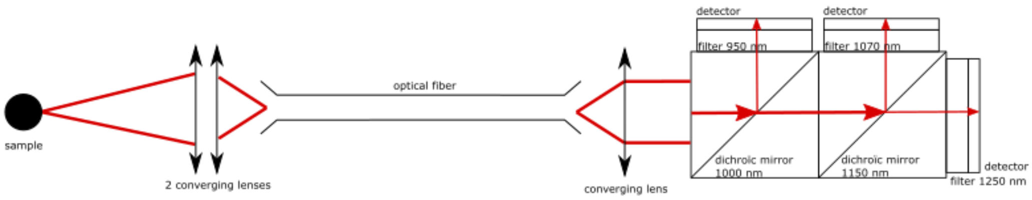

Figure 1. Sketch of the three-colour pyrometer.

The signal measured by the pyrometer at the wavelength λ_i is expressed assuming Wien's approximation:

$$S_i = f_i \epsilon_i C_1 \lambda_i^{-5} \exp\left(-\frac{C_2}{\lambda_i T}\right) \quad (1)$$

with f_i a specific function of the pyrometer, ϵ_i the directional spectral emissivity at the wavelength λ_i, $C_1 = 3.741 \times 10^8$ W·µm^4·m^{-2}, C2 $=$ 14 388 µm·K and T the temperature. We can define the linearized ratio of signals S_i at wavelengths λ_1 and λ_3, equation (2), and the signal S_2 at wavelength λ_2, equation (3):

$$\ln\left(\frac{S_1}{S_3}\right) = \ln\left(\frac{\varepsilon_1}{\varepsilon_3}\right) + K_2 + \frac{K_1}{T} \quad (2)$$

$$\ln(S_2) = \ln(\varepsilon_2) + K_4 + \frac{K_3}{T} \quad (3)$$

where K_1, K_2, K_3 and K_4 are four coefficients determined through calibration with a blackbody. For a blackbody, the emissivities ϵ_i are taken equal to one, the equations (2) and (3) are then simplified and Figures 2 and 3 show the identification of coefficients K_i.

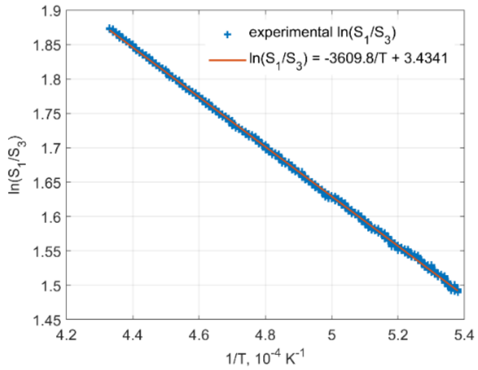

Figure 2. Estimation of the coefficients K_1 and K_2 during measurement with a blackbody.

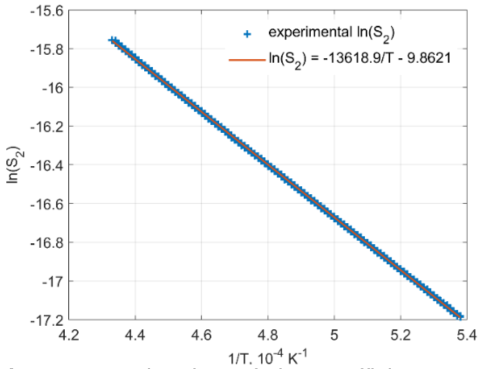

Figure 3. Estimation of the coefficients K_3 and K_4 during measurement with a blackbody.

Once the blackbody calibration is realized, equation (2) is used to compute the temperature during the experiment. The ratio ϵ_1/ϵ_3 is determined on the solidification plateau, knowing the melting temperature, and is assumed to remain constant. Once the temperature is computed with equation (2), equation (3) is used to compute the normal spectral emissivity ϵ_2, and then the absorptivity according to Kirchhoff's law. The results on liquid iron samples are presented Figure 4.

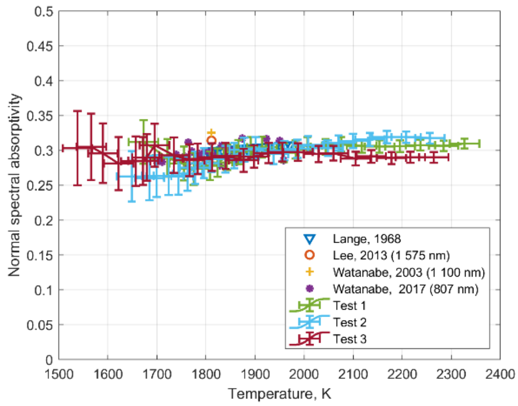

Figure 4. Normal spectral absorptivity of liquid iron over temperature and comparison with literature.

References

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[3] Maelenn Le Mener, Coline Bourgès, Elodie Courtois, Thomas Pierre, Mickaël Courtois, *A new approach for determining the specific heat of liquid metal at high temperatures by aerodynamic levitation*, International Journal of Thermophysics (2026) 47:8.

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