TEMPERATURE FIELD FROM FREE TWO PHASE JET USING INFRARED EQUIPMENT

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REZUMAT. Lucrarea tratează utilizarea metodei de analiza în infraroșu a câmpului de temperaturi dintr-un jet de ceață de apă. Elemente privind erorile de măsurare a temperaturii în infraroșu, comparativ cu metodele de măsurare directă, sunt prezentate în lucrare. Ca rezultat al acestui mod de evaluare a radiației s-a obținut caracteristica de emisivitate a mediului. A fost pusă în evidență influența temperaturii, a umidității relative precum și a grosimii stratului dintre camera și obiectul vizat. Pe aceasta baza s-au obținut parametrii de setare a camerei în funcție de proprietățile mediului. Testele au fost realizate pe un jet cald de lichid în evaporare, generat de un ajutaj convergent. Principala conclusie a lucrării o constituie faptul că metoda de măsurare a temperaturii în infraroșu trebuie corectată pe baza valorilor obținute prin măsurătorile directe, în special în cazul mediului cu ceața. Pe această bază calculul fluxurilor de energie schimbate de obiectele sau mediile supuse analizei sunt mai precise.

Cuvinte cheie: metodă infraroșu; jet bifazic; erori de temperatura; evaluarea energiei

ABSTRACT. The paper treats the use of infrared method in aim to evaluate the temperature field in water mist jet. The elements concerning the errors of temperature measurement due to the infrared method in comparison with direct contact method are shown. As the result of this assessment the radiation emission of analysed structure was found. Also, the influence of the depth of the air-fog layer and of the relative humidity is analyzed. The results show that an assessment of a field temperature, using infrared method, requires the adequate correction of the red values on the apparatus screen. These findings explain why there are a lot of inadequate values if the preset emission factor does not take into consideration the environmental two-phase composition and distance between the infrared camera and the main target. The tests were realised on the water mist jet is created from plain water, forced in special nozzles. The main conclusion of the paper resides in the fact that the infrared method must be used with the specific corrections of temperature values based on the direct measurement. On this way the calculated heat fluxes and the energy assessment of the subjected equipment are more accurate.

Keywords: infrared method; two-phase jet; temperature errors; energy assessment.

1. INTRODUCTION

The infrared radiation is that portion of the electromagnetic spectrum that extends from the long wavelength and end of the visible-light range. Invisible to the eye, it can be detected as a sensation of warmness on the skin. The infrared range is usually divided into three regions: near infrared (nearest the visible spectrum), with wavelengths 0.78 to about 2.5 µm, middle infrared, with wavelengths 2.5 to about 50 µm and far infrared, with wavelengths 50 to 1 000 µm. Most of the radiation emitted by a heated surface is infrared; it forms a specific spectrum [1-3]. Molecular excitation also produces numerous infrared radiation but in a discrete spectrum of lines or bands.

In infrared thermal imaging, the temperatures are computed from the measured IR radiation according to Planck’s law, modified by corrections due to the camera characteristic (detector response, transmission of optics etc.), as well as to the emitter, e.g. the object under consideration. The major problems in quantitatively interpreting surface temperatures from objects are due to the latter correction, which is described by the emissivity of the objects. Its value is an input parameter, adjustable at the camera and in the analysis software and requires additional knowledge of the system under study. For most objects, emissivities refer to the grey bodies and are assumed to be constants (with values ranging around 0.8). In this case, small variations in the emissivity value lead only to minor changes of the resulting surface temperatures.

The infrared absorption and emission characteristics of molecules and materials yield important information about the size, shape, and chemical bonding of molecules and of atoms and ions in solids. The energies of rotation and vibration are quantized in all systems. The infrared radiation energy emitted or absorbed by a given molecule or substance is therefore a measure of the difference of some of the internal energy states. For this reason, infrared spectroscopy is a powerful tool for
determining the internal structure of molecules and substances or, for identifying the amounts of those species in a given sample [2,4].

Also, the infrared radiation plays an important role in heat transfer and is essential to greenhouse effect.

2. INFRARED RADIATION ATTENUATION IN GAS AND VAPOUR MEDIUM

This section put in evidence only the radiation particularities of so called visible transparent medium. Due to the fact that the thermograph measurement is a non contact method, we have a certain distance between the infrared apparatus and the body target. In general this space is full field by the gas phase. This medium consists in a mixture of bi-atomic and mainly tri-atomic gas compounds as CO₂, H₂O and the trace of other gaseous compounds. It is well known the tri and polyatomic gases emit and absorb in the infrared field [1]. Also, the liquid droplets or solid particulates, dust, soot or ice crystals, have a sensible influence of the infrared transmissivity [2-4]. The adequate law for propagation in function of the distance between the source and reflective body is the Lambert Beer law [2, 3, 5]. This states quantitatively the absorption of radiation and is expressed by [3]:

\[ I(\lambda) = I_0(\lambda) \exp\left(-\sigma(\lambda) c L\right) = I_0(\lambda) \exp\left(-\kappa \lambda \frac{L}{c}\right) \quad (1) \]

where: \( I(\lambda) \) is the intensity after passing through a layer of thickness \( L \), while \( I_0(\lambda) \) denotes the initial intensity emitted by the source, and \( c \) is the gas concentration. The quantity \( \sigma(\lambda) \) denotes the absorption cross section at the wavelength \( \lambda \); it is a characteristic property of any species. The absorption cross section \( \sigma(\lambda) \) can be measured in the laboratory, while the determination of the light path length \( L \) is insignificant in the case of the arrangement of an artificial light source and detector. The constant of proportionality, \( \kappa = \sigma(\lambda) c \), is called the spectral absorption coefficient of the medium, in \( \text{m}^{-1} \). Consequently, an attenuation of the radiation beam travelling an absorbing medium of thickness \( L \) occurs. According with the Beer’s law the spectral transmissivity results:

\[ \tau(\lambda) = \exp\left(-\kappa \lambda \frac{L}{c}\right) \quad (2) \]

The spectral absorptivity, and emissivity, according with the Kirchoff law, is:

\[ \alpha(\lambda) = \varepsilon(\lambda) = \tau(\lambda) = \exp\left(-\kappa \lambda \frac{L}{c}\right) \quad (3) \]

The above radiation coefficients vary with the temperature, wavelength, pressure and composition of the concerned medium.

3. TEMPERATURE PROFILE OF THE FREE TWO-PHASE JET USING INFRARED EQUIPMENT

This section provides practical results using an infrared camera for a warm two-phase jet. The experimental tests were realised in a closed space, in aim to avoid the surrounding modification of the medium. The water mist is created from plain water forced through special nozzles. In order to correctly evaluate the temperature profile in the developed water mist jet and to minimize the measurement error, there are several factors that must be properly corrected, such as emissivity, apparent reflected temperature, thermal contrast and the distance from camera to target [6,7].

The first step when freezing a thermal image is to measure the apparent reflected temperature. The way this is done consists by setting the emissivity to \( \varepsilon = 1 \), the distance to \( L = 0 \) and by pointing the camera to an aluminium sheet which has a reflectance of 0.96. What happens is that the camera will capture all the radiation coming from the environment. The value read is \( T_{amb} = 28 \, ^\circ\text{C} \) and it will be automatically compensated by the camera once introduced as a correct parameter. It should not be confused with the ambient temperature, since an infrared camera does not measure temperature, but radiation. This will further ensure a correct emissivity measurement.

The emissivity measurement is critical, since without a correct emissivity measurement, the real temperature cannot be measured. The way this was done involves a direct method. This procedure consists of measuring the water temperature with a thermo-couple, directly at the nozzle outlet. The real temperature is read as \( T = 42^\circ\text{C} \). After that, the emissivity factor was adjusted, until the temperature read on the apparatus screen coincided with the new obtained value. By this procedure, the mist emissivity factor of \( \varepsilon = 0.92 \), was determined [8]. Also, using the direct contact equipment other parameters such a relative humidity and atmospheric temperature were measured and updated.

The figure 1 display a mist jet infrared image captured with the camera. The temperature scale is on the right band. The extrem temperature values were also printed on the figure. The table 1 contains the camera parameter set for the captured image displayed in the figure 1.

From the figure 1 it is observable that at the high value of temperature the field reading is very close to reality, since the measurement error significantly increases as emissivity decreases. The temperature values were read at several emissivity points with a step of 0.05 under our real value of 0.92, and the measurement errors were calculated.
The graphic displayed on the figure 2 shows that for an emissivity difference of 0.40 the relative error for the temperature measurement is 25% (the adopted scale is in Celsius degree). For the analyzed case, under the emissivity factor of $\varepsilon=0.5$, it is not recommended to do measurements.

![Image of infrared image of mist jet](image)

**Fig. 1.** Infrared image of mist jet.

<table>
<thead>
<tr>
<th>Camera set operating parameters</th>
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<tbody>
<tr>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td>Emissivity</td>
</tr>
<tr>
<td>Object distance</td>
</tr>
<tr>
<td>Ambient temperature</td>
</tr>
<tr>
<td>Atmospheric temperature</td>
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<tr>
<td>Relative humidity</td>
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</table>

**Table 1**

The temperature evolution along the water mist on the central axis is shown in the figure 3, respectively along the outer limit axis in figure 4. From both figures we observe that the local mist temperature decreases exponentially with the distance from the jet nozzle. The analogue shape of these evolutions was obtained using the direct contact measurement methods.

![Figure 3. Temperature variation in the mist jet axis.](image)

**Fig. 3.** Temperature variation in the mist jet axis.

![Figure 4. Temperature variation on the mist jet boundary.](image)

**Fig. 4.** Temperature variation on the mist jet boundary.

For a better understanding of how the water-mist temperature field and heat flow develop, the lower and higher temperature scale limits where optimized in order to achieve the best thermal contrast. This is best done on the computer by adjusting the level/span. The images shown in the figure 5 display the water-mist behavior.

Some random points on the image where chosen to read their temperature values, on a high contrast color palette. The pattern from the figure 6 based on the temperature scale gives us the view layers composing the mist jet.

The final analysis is a tool called histogram, where temperature distribution inside the water mist area is shown (figure 7).

**CONCLUSIONS**

The main factors concerning the infrared characteristic were studied. The dominant parameter influence for the temperature values accuracy is the distance between the camera objective and the target. The medium radiation absorption coefficient is a key parameter in the correct temperature evaluation by the thermal camera.

The emissivity of the medium in function of its composition and the distance was determinate using
the direct method measurement. The pattern of the mist jet was displayed, and by the temperature field the calculus of the heat fluxes are possible.

The data provided by the infrared mist jet analysis help us to correct the theoretical simulation of specific transfer processes. By using the infrared camera the fluid and energy flows assessment of the subjected equipment are more accurate.

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