A METHOD OF DETERMINING TEMPERATURE FIELDS WITH AN INTERFEROMETER

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A method of determining temperature fields using an interferometer is described. A new formula is presented for calculating temperatures from interferograms. Data obtained on the interferometer are compared with data obtained by other methods.

Optical methods of investigation have recently become more widely employed in heat and mass transfer studies. In thermal processes, the interest usually lies in determining the distribution of temperature and heat flux in the space investigated. The determination of these parameters by the usual methods using thermal probes is a very laborious and lengthy task. Moreover, the insertion into the medium investigated of a specially constructed sensor distorts the thermal and hydrodynamic processes at that point. The readings of thermal probes are affected by radiation, the finite dimensions of the probe, conduction along the leads, the construction of the holder, etc.

Optical methods are free of defects of this kind. Their advantages are as follows: a) preservation of the flow structure; b) freedom from inertia, i.e., the ability to record instantaneously changes occurring in the space investigated; this is especially important in connection with unsteady processes; c) high accuracy and speed of measurement; d) possibility of visual observation of the process.

The most convenient optical method of investigation is the method using an interferometer. This gives an instantaneous picture, in terms of isotherms, of the temperature distribution throughout the whole of the field examined, and also the temperature profiles in the medium, from which local heat transfer coefficients may easily be determined.

The interferometer method is used to investigate plane or axisymmetric problems, since a ray of light passing through the space investigated gives an average value of its characteristics.

Determination of temperature fields using the interferometer began essentially in 1932, when a formula was proposed by Kennard [1] for the temperature difference between two points of a field. This formula was later simplified by Soehengen [2].

Both these methods are quite laborious, since, to determine temperature from the formula proposed in [1], the refractive index n of the medium must be known, and when using the formula given in [2] the density ρ, which depends on the pressure in the medium P. Therefore, to determine temperatures by the above methods, it is necessary to construct special nomograms of the type

$$n = f(P,\ T) \quad \text{or} \quad \rho = f(P,\ T).$$

This paper gives a more convenient formula for calculating the temperature field from a given pressure and temperature at a definite point in the space under investigation.

Interpretation of the interferometer picture. The refractive index of dry air is related to its temperature and pressure by the following equations [3]:

$$n = 1 + B/T, \tag{1}$$

where

$$B = 8.8 \cdot 10^{-5} P.$$

Assuming that the pressure does not change during the experiment, and differentiating (1) with respect to T, we obtain

$$dn = -BdT/T^2. \tag{2}$$

The "minus" sign shows that the refractive index increases as the temperature decreases.

The change in optical path difference in different parts of the medium examined is given by the formula

$$\delta\Delta = \Delta_1 - \Delta_2 = l\,(n_1 - n_2) = l\,\delta n. \tag{3}$$

Expression (2) for the same parts may be written as follows:

$$\delta n = -B\,\delta T/T^2. \tag{4}$$

From (3) and (4) we obtain

$$\delta T = -T^2 \delta\Delta / lB. \tag{5}$$

Since in passing from fringe to fringe on the interferogram, on the isotherms, the path difference of the rays changes by one wavelength λ, this formula may be written:

$$\delta T = -T^2 \lambda / lB. \tag{6}$$

Expression (6) is the temperature difference between two adjacent light or dark bands. Therefore, knowing the temperature at any band, we can determine the value for an adjacent band from

$$T_1 = T \pm |\delta T| = T \pm |AT^2|, \tag{7}$$

where

$$A = \lambda / lB.$$

The absolute value of δT is taken, since the temperature to be determined may be greater or less than the known temperature by δT, depending on the experimental arrangement.

Clearly, at the second, third, etc. bands, the temperature will be, respectively

$$\begin{aligned} T_2 &= T_1 \pm AT_1^2 = T \pm [AT^2 + A(T + AT^2)^2]; \\ T_3 &= T_2 \pm AT_2^2 = T \pm \{AT^2 + A(T + AT^2)^2 + \\ &+ A[T + AT^2 + A(T + AT^2]^2\} \\ &\cdots\cdots\cdots \end{aligned} \tag{8}$$

Thus, at the k-th band, the temperature, with sufficient accuracy for engineering purposes, will be

$$T_k = T \pm [kAT^2 + k(k-1)A^2T^3 + k(k-1)(k-1.5)A^3T^4 + \ldots]. \tag{9}$$

It should be noted that, in deriving this formula, the pressure was assumed to be constant throughout the field examined. Formula (9) may therefore be used in investigating the phenomena associated with natural convection, and also forced convection, when the change of pressure in the direction of flow can be neglected. In cases when the pressure along the flow varies quite appreciably, the value of the pressure appropriate to each section must be inserted in (9) (under conditions of no pressure variation across the flow).

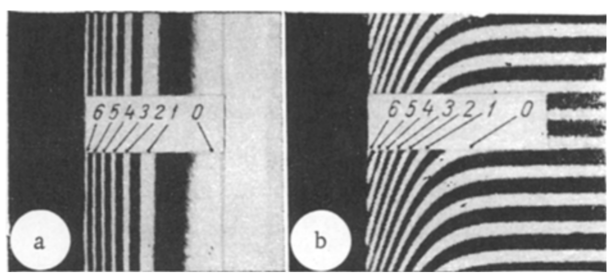

Fig. 1. (a) Temperature field showing isotherms near a heated vertical plate (0 – light field beyond limits of boundary layer; 1, 2, 3, 4, 5, 6 – respective numbers of bands from zero); (b) temperature profile in front of a heated vertical plate.

Interferograms (Figs. 1 and 2) are given as examples of temperature calculations based on (9). The temperature at

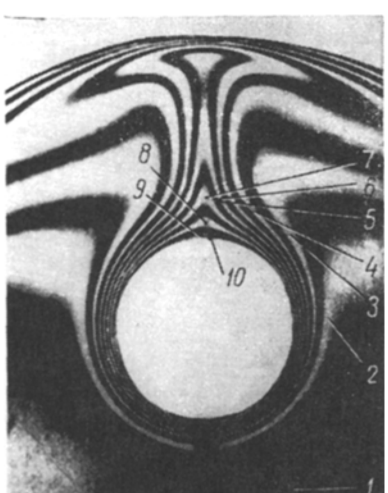

Fig. 2. Isotherms of the temperature field in a closed space: 1 – T = 20.6°C; 2 – 21.9; 3 – 23.1; 4 – 24.6; 5 – 26.1; 6 – 27.5; 7 – 29.0; 8 – 30.2; 9 – 31.7; 10 – 33.3.

the zero band (Fig. 1a) will equal that of the surrounding air. Knowing the parameters entering into (9), the temperature at the k-th band may easily be determined.

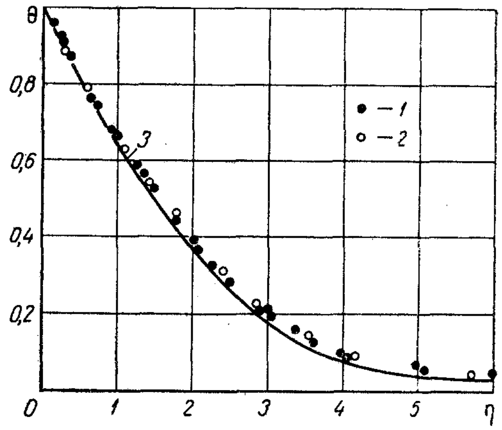

Fig. 3. Variation of dimensionless temperature θ with coordinate η: 1 – Soehengen's data; 2 – data obtained from formula (9); 3 – temperature profile curve according to Polhausen.

In Fig. 1b the bands, distorted owing to temperature variations with the boundary layer, form a temperature profile. Points 1, 2, 3, etc. indicate how far, expressed in band thicknesses, the bands have been displaced from their initial values. Knowing the temperature of the surrounding air (point 0), we can easily determine that at any point k.

The interferogram of Fig. 2 shows the temperature field at the isotherms around a cylindrical heater situated in a confined space. Under the heater there is a zone with temperature equal to that of the surrounding medium. The temperature distribution over the heater perimeter and the temperature field were calculated according to (9), and the results compared with the readings of thermocouples located on the heater surface. The temperature of the surrounding medium was taken as the initial temperature in (9). The calculated heater temperature showed good agreement with the thermocouple readings.

The temperature field obtained with the aid of an interferometer agrees quite well with experiments and with the exact theoretical solutions for natural convection and a laminar boundary layer (Fig. 3).

NOTATION

n, P, and T – refractive index, pressure, and temperature of medium under investigation; l – model length; Δ – difference in ray path in limbs of interferometer; λ – wavelength for monochromatic light.

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