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ACCURACY OF DETERMINATION OF THE DENSITY OF A GAS BY THE MULTIBEAM-INTERFEROMETRY METHOD

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We estimate the accuracy of the determination of the density of a gas in rarefied streams by using the photometric method of multibeam interferometry. We give the numerical values of the relative error in the measurements for various experimental conditions.

Measurement of the density of rarefied gas streams may be carried out by the method of multibeam interferometry [1], based on the multiple passage of a beam of light through the gas stream investigated. The special feature of the method is that the measurements are more sensitive than in the case of two-beam interferometry, so that quantitative investigations can be made in streams at a static pressure of as little as $1\text{-}5 \cdot 10^{-2}$ torr [2, 3], and, in particular, it is possible to determine the shape of the density jump, the start and thickness of the shock wave, etc.

In what follows, we shall estimate the accuracy of density measurements beyond the jump by the multibeam-interferometry method, with the interferometer adjusted to a field of equal illumination (a "band of infinite width") and with photometric decoding of the interferograms [2, 3].

The density ρ_2 beyond the jump is defined in general form as

$$\rho_2 = \rho_1 + \Delta\rho, \tag{1}$$

where ρ_1 is the density of the incoming stream; $\Delta\rho$ is the increment of density, which has the form [3]

$$\Delta\rho = \frac{2.3\,\Delta D_2 \varepsilon}{\gamma} \cdot \frac{(1 + 2.3\,\Delta D_1/\gamma)^2}{(2.3\,\Delta D_1/\gamma)^{1/2}}, \tag{2}$$

where ε is a coefficient that is constant for a given measurement and depends on the wavelength of the monochromatic light, the reflection coefficient of the mirrors, and the distance between them [3]; ΔD_1 and ΔD_2 are the values of the optical densities of blackening of the photographic material at the measured points of the field in the incoming-stream region and beyond the jump, respectively.

The relative error in the density measurements can be represented as

$$\frac{\Delta\rho_2}{\rho_2} = \frac{\Delta(\rho_1 + \Delta\rho)}{\rho_1 + \Delta\rho} = \frac{\Delta\rho_1}{\rho_1} \cdot \frac{1}{1 + \frac{\Delta\rho}{\rho_1}} + \frac{\Delta(\Delta\rho)}{\Delta\rho} \cdot \frac{1}{1 + \frac{\rho_1}{\Delta\rho}}, \tag{3}$$

and, consequently,

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TABLE 1. Relative Errors of Determination of the Density of a Gas for Various Accuracies of Measurement of Blackening and Contrast Coefficient of the Photographic Material

$\frac{\Delta(\Delta D)}{\Delta D}$	0,01		0,02		0,03	
$\frac{\Delta\gamma}{\gamma}$	0,02	0,03	0,02	0,03	0,02	0,03
$K_1 = 0{,}5$, $K_2 = 0{,}5$	0,025	0,03	0,04	0,045	0,055	0,06
$K_1 = 1{,}5$, $K_2 = 2{,}5$	0,075	0,10	0,10	0,125	0,125	0,15

$$\frac{\Delta(\Delta\rho)}{\Delta\rho} = \frac{4.6\,\Delta D_1/\gamma}{1 + 2.3\,\Delta D_1/\gamma}\left[\frac{\Delta(\Delta D_1)}{\Delta D_1} - \frac{\Delta\gamma}{\gamma}\right] + \frac{\Delta(\Delta D_2)}{D_2} + \frac{1}{2}\cdot\frac{\Delta\gamma}{\gamma} - \frac{1}{2}\cdot\frac{\Delta(\Delta D_1)}{\Delta D_1}. \quad (4)$$

From (4) it can be seen that the total error is given by the error of measurement of the difference in optical densities and the contrast coefficient of the photographic material.

We rewrite (4) in the form

$$\frac{\Delta(\Delta\rho)}{\Delta\rho} = K_1\left|\frac{\Delta(\Delta D_1)}{\Delta D_1}\right| + \left|\frac{\Delta(\Delta D_2)}{\Delta D_2}\right| + K_2\left|\frac{\Delta\gamma}{\gamma}\right|, \quad (5)$$

where

$$K_1 = \frac{3.45\,\Delta D_1/\gamma - 0.5}{1 + 2.3\,\Delta D_1/\gamma}, \quad (6)$$

$$K_2 = \frac{5.75\,\Delta D_1/\gamma + 0.5}{1 + 2.3\,\Delta D_1/\gamma}, \quad (7)$$

where the values of K_1 and K_2 are in the ranges $K_1 = 0.5$–1.5 and $K_2 = 0.5$–2.5. In Table 1 we give the relative errors $\Delta(\Delta\rho)/\Delta\rho$ for various accuracies of measurement of ΔD and γ.

It can be seen from Table 1 that the predominant contribution to the total error of the measurements of $\Delta\rho$ is made by the error in the measurements of ΔD and γ; as $\gamma/\Delta D \to 0$ the value of $\Delta(\Delta\rho)/\Delta\rho$ decreases.

Taking account of the fact that the error in the determination of the density of the incoming stream, on the basis of temperature and pressure measurements, does not exceed 5%, we find from (3) for a maximum error in the measurements of the blackening density ($K_1 = 1.5$, $K_2 = 2.5$) that

$$\frac{\Delta\rho_2}{\rho_2} = 0.05\,\frac{1}{1 + \frac{\Delta\rho_1}{\rho_1}} + 0.15\,\frac{1}{1 + \frac{\rho_1}{\Delta\rho_1}}, \quad (8)$$

which yields a total error of no more than 6%. For a crude determination of the density ($\Delta\rho_1/\rho_1 = 8\%$) the total error in the measurements increases to 10%.

The estimates given above refer to the case of two-dimensional flows. When we determine the density in axially symmetric flows, using a parabolic approximation of the experimental function $\Delta D = f(r)$, where r is the radius of the stream, and select a sufficiently large number N of annular zones (for example, $N \geq 10$), the accuracy of the measurements is worse by only 1-2% [4, 5].

Thus, the photometric multibeam-interferometry method provides satisfactory accuracy in the determination of density fields in supersonic rarefied gas streams in a region of flow with slippage.

NOTATION

ρ_1, density of gas in the incoming stream; ρ_2, density of gas beyond the jump; $\Delta\rho$, increment of density; r, radius of nonuniformity; ΔD, difference between optical blackening densities; ε, coefficient; γ, contrast coefficient of the photographic material.

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HEAT AND MASS TRANSFER IN THE FLOW OF CONDENSABLE RAREFIED GASES THROUGH POROUS MATERIALS

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Heat and mass transfer in the flow of a condensable vapor through porous materials with substantially different thermophysical parameters is investigated at pressures below the triple point.

In technological processes involving the vacuum distillation and purification of materials, and in vacuum sublimation drying, problems of heat and mass transfer in the condensation of vapors into the solid state become very important. This is particularly true of the problem of the total recovery of the evolved vapors. At the present time, the foremost problem is the development of technological processes and devices for separating a vapor—gas mixture and completely recovering the condensable vapor. The uncondensable component of the mixture must be drawn off with a vacuum pump. This formulation of the problem is not dictated by purely economic considerations in working with vapors of valuable materials, but also involves problems of safety procedures and the prevention of atmospheric contamination in working with corrosive, dangerously explosive, and toxic vapors.

The purpose of the present investigation is to study heat and mass transfer in the flow of condensable vapors through porous materials with various thermophysical parameters at pressures below the triple point and to develop recommendations on the production of permeable porous barriers for vacuum condensers. To do this we devised a research procedure and built an experimental setup.

The experimental setup shown schematically in Fig. 1 was mounted in a temperature and pressure controlled test chamber made of stainless steel and having the necessary thermal lead-ins and a viewing port. A pan vaporizer 3 with an electric heater 4, whose power could be controlled, was mounted on the laboratory balance 1. A flux of vapor was produced by the sublimation of naphthalene. The porous sample 5 was attached to the base of cylinder 6 which was fastened to laboratory balance 2. The pan vaporizer 3 and cylinder 6 were made of Duralumin. Cavity A was filled with VM-4 vacuum oil, forming a hydroseal which ensured independent displacement and recording of the weight of pan 3 and cylinder 6 on balances 1 and 2, respectively.

The pressure in the test chamber was maintained at $5 \cdot 10^{-2}$ mm Hg and recorded by two VT-3 (7) thermocouple vacuum gages; the pressure in space B was determined by the temperature of saturated naphthalene vapor. The temperature of the material being sublimed, the porous sample, the nitrogen plate, the medium, and the walls of the test chamber were monitored with differential copper—Constantan thermocouples. The emfs of the thermocouples were recorded by a type M25 high-sensitivity mirror galvanometer in a circuit with a PMS-48 low-resistance potentiometer.

The porous materials used were single and multilayer felt, stainless steel, porous graphite, and a bulk porous material consisting of glass beads.

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