JET FLOWS DURING SUBLIMATION IN A VACUUM BY THE METHOD OF SCHLIEREN PHOTOGRAPHY*

D. P. Lebedev and V. V. Uvarov

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The methodology of investigating jet flows during sublimation in a vacuum by the schlieren photography method is considered.

P. D. Lebedev first used schlieren photography to investigate and analyze heat and mass transfer during evaporation and drying in [1]. Known attempts to use schlieren, as well as interference, photography to investigate jet flows over the surface of ice and capillary-porous bodies during sublimation in a vacuum (e.g., to analyze mass transfer during sublimation drying) led a number of authors to a deduction about the limited possibilities of this method and to the proposition that it be used only to residual pressures of 10 mm Hg [2, 3]. As we mentioned in [4], such a conclusion is evidently justified by the fact that the experiments represented in [2] were conducted under low-intensity energy supply, and were accompanied by negligible perturbations in the external medium (at the sublimation surface). Moreover, these investigations were in ordinary laboratory sublimers, where such experiments were either not provided for preliminarily, or it was impossible to set up the adjustment needed for the corresponding optical system.

We worked out the construction of the apparatus and the methodology of the experiment to permit a significant extension of the possibility of using schlieren photography in the reduced pressure domain.

Experimental Apparatus and Investigation Methodology

The experimental apparatus (Fig. 1) for the investigation of external mass transfer during sublimation by the schlieren photography method has an optical cuvette 1 whose construction provided for the production of a given vacuum and the organization of exact adjustment of the optical windows 2.

The primary goal was achieved by fabricating sealed connections in the cuvette by using the fundamental construction recommendations of vacuum engineering [7], and the second goal by using elements permitting rapid adjustment (e.g., bolts with fine threading, set and regulating screws, etc.) and mounting of the whole apparatus on the coordinate table 9 of the autocollimator.

The quartz windows 2 of the cuvette 1 were installed with high accuracy in a parallel beam of rays by using the autocollimator according to the method elucidated in [8]. A certain relatively parallel location was first achieved by using tightening of the nuts of the leakproof bolts. Coincidence of the individual images of the point light source was the criterion for strict parallelism of the two cuvette windows.

A cylindrical housing 8 with the material being investigated was placed at the center of the bulky aluminum jacket of the cuvette 1. Ice, sand, and products of the food industry were used as this material. A flat cylindrical heater 5 connected to the wattmeter 7 type D-5004 and powered through a regulatable autotransformer (latr) from the grid was mounted at the base of the housing. The vacuum-system connecting pipe was mounted in the jacket of the cuvette 1 above the surface of the cylindrical housing.

The material, first frozen in the housing 8, was placed in the cuvette where a residual pressure of 0.75 mm Hg was produced by the mechanical vacuum pump 6. The vacuum was measured by a standard membrane vacuum meter 3.

*This paper is a continuation of [5, 6].

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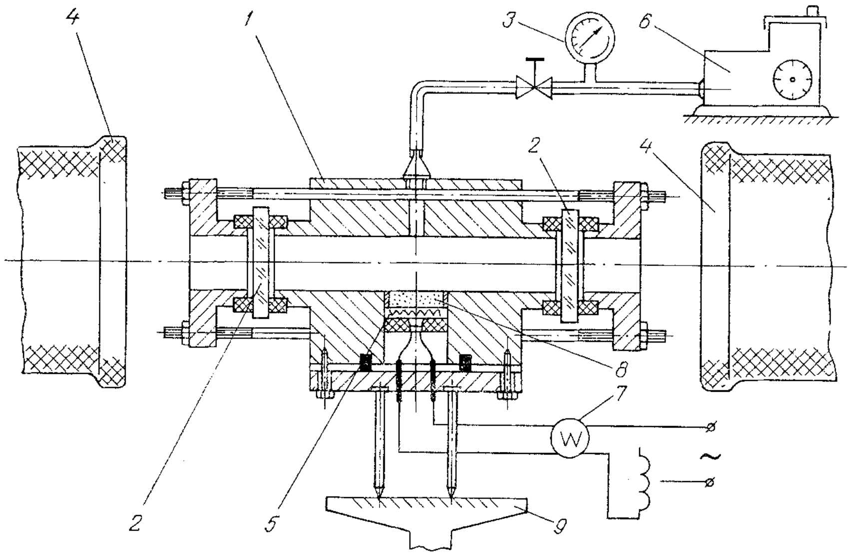

Fig. 1. Schematic diagram of the experimental apparatus.

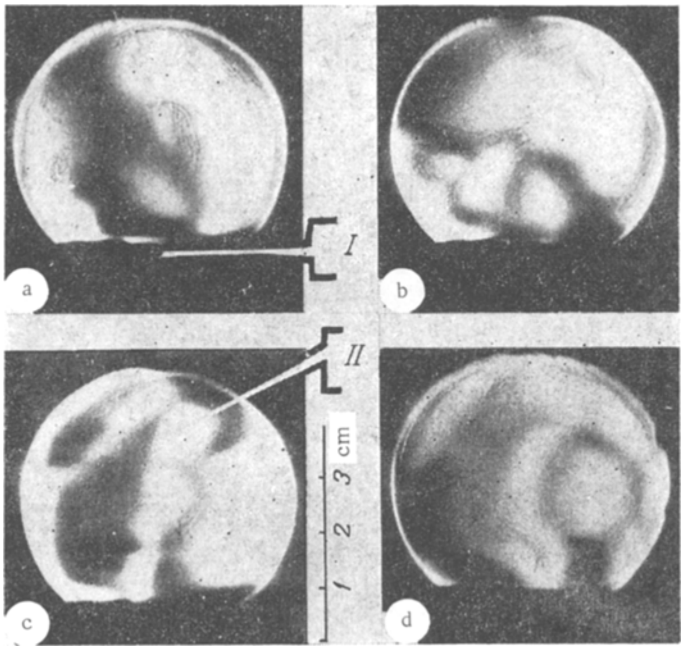

Fig. 2. Shadowgraphs of jet flows above the surface of subliming sand: a) τ = 21 min; b) 23; c) 24; d) τ = 26 min (I — sublimation surface; II — jet of vapor). P = 0.75 mm Hg, and $q \approx$ 3000 W/m^2.

The experimental cuvette 1 was mounted on the coordinate table 9 of the autocollimator, between the lenses 4 of the IAB-451 schlieren device in a parallel light beam. An SDVSh 250-3 mercury lamp was the light source of the IAB-451 schlieren device. The width of the optical slit in the IAB-451 schlieren device was selected by test within 0.1-1-mm limits. The reflex camera Zenit-3M was taken as photographic apparatus.

Hypersensitized film ORWO-27 was used for the photography. The special hypersensitization significantly increased not only the spectral but also the general sensitivity of the photographic film [9].

A given quantity of energy delivery ($\sim$3000 W/m^2) was set by using the autotransformer in wattmeter 7.

The development of the sublimation process was constantly monitored visually through the optical reflex system of the photographic apparatus and the schlieren device. The jet flows observed above the sublimation surface were exposed on the photographic film after given time intervals. The schlieren pattern of the cycle of jet flow formation is shown in Fig. 2 for contact sublimation drying of the sand. As mentioned in [4, 10], the internal mechanism of the sublimation process for moisture frozen in the material was determined to a considerable degree by the formation of microdomains on the heated surface filled with vapor, which was ejected into the vacuum periodically in the form of ordered jet flows for appropriate pressures in the dehydrated channels (microcracks) or micropores of the material. It is seen from Fig. 2 that the jet flows were localized and pulsating in nature (Fig. 2d) throughout the whole sublimation process, and the profile of the jets took on a quite extraordinary shape (Figs. 2a-c). Analogous patterns were observed even when other materials were used instead of frozen sand.

Analysis of the results obtained permits the assumption that disordered local velocity and pressure gradients will occur periodically along the surfaces of the radiator—emitter and the product under conditions of sublimation and combined (contact-radiation) energy supply [4]. Some investigations of the velocity fields above the sublimation surface are represented in [5, 6, 10].

The results obtained and the whole complex of representations about the mechanism of external mass transfer during sublimation in a vacuum [5, 6, 10] should be taken into account in theoretical extensions and practical recommendations for the organization of a radiation and a combined energy supply.

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