# APPLICATION OF THE SCHLIEREN METHOD IN STUDIES OF THE TEMPERATURE FIELD IN A LIQUID ABOVE A PLATE WITH A MOVING HEAT SOURCE

Yu. N. Lyakhov (Perm)

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The schlieren shadow method is widely used for experimental investigations of thermal and hydrodynamic phenomena. In the vast majority of works known, it has been used for the study of gas flows and only in some cases [1-3] for liquids. The sensitivity of the schlieren method applied to liquids is much greater, while its accuracy is at least no worse than in the case of gases. According to the estimate of [1], for the same values of $\partial \ln \rho / \partial n$ in water and air ($\rho$ is the density of the medium, and the derivative is taken normal to the light ray), the curvature of the ray in water is $10^3$ times greater than in air. The authors of [1] obtained a sharp schlieren image in water at a temperature difference of 0.05°. The heat dissipation of a horizontal isothermal plate in air and of another vertical plate in water was examined in [2]. Comparison of the results of the optical method with direct measurements of the power delivered to the plate revealed a 6% discrepancy for the first case and a discrepancy of about 4% in the second case. This is a satisfactory agreement for thermal experiments.

It seems that the schlieren method has never been used for examining the temperature field created in a liquid by a moving heat source. The following is a study of the free convection in a liquid above a thin plate in which a temperature field was created by means of a moving point source of heat.

A 1.5 mm thick plate of 1Cr13 stainless steel formed the bottom of tray 4 with plane parallel plexiglas walls (Fig. 1). The bottom of the plate was thermally insulated; the upper side was in free contact with distilled water. A heat source resulted from the local heating of the bottom of the tray at the point of contact 7 with a graphite electrode which was connected over the plate to the secondary winding of a transformer. The electrode was uniformly shifted over the bottom of the plate along a long, slitlike cut in a thermally insulating layer (i.e., in the direction of the x-axis).

The diagram and detailed description of the arrangement with the moving heat source appeared in [4]. The tray was placed into the view field of a usual schlieren system with a parallel light beam created with a collimator and the optical bench OSK-3. The aberration-free schlieren lens $L_2$ had a focal length F = 53 cm, which is quite adequate [3] for obtaining the necessary sensitivity. Grid 5, produced with a photographic technique, has 1 mm thick mesh bars spaced 1 mm apart and was placed in the focal plane of lens $L_2$. To reduce the size of the setup, an additional lens $L_3$ of short focal length was placed between the grid and the photographic camera 6. A 300 W incandescant lamp was the light source; this lamp illuminated slit 3 of collimator $L_1$ through condenser 2. The width of the slit could be varied from 0.1 to 0.2 mm. Photographs of the schlieren imagine 8 were made with a "Zenit" camera using a "Helios-40" objective and intermediate rings. The exposure time was 1/30 sec at a source-displacement speed of 0.96 mm/sec and 1/60 sec at a speed of 2.4 mm/sec.

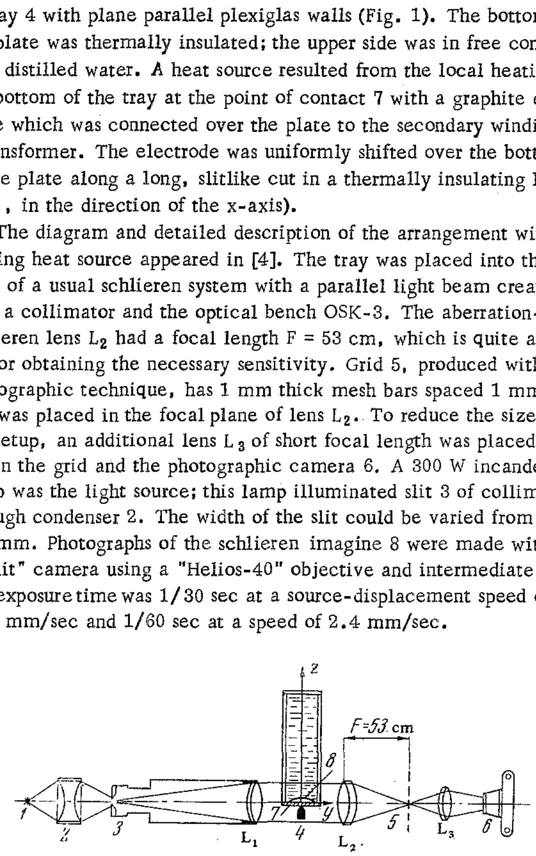


Fig. 1

Figure 2 is a schlieren photograph of the moving temperature field in the water above the horizontal plate. The source power was 4.88 W and the speed of the source 0.96 mm/sec. The source moves to the left. The isophots are lines of equal temperature gradients normal to the plate (the collimator slit and the grid are parallel to the plate). The asymmetry of the thermal boundary layer in the direction of source motion and, above the source, the thermal flare in the form of one isoline of the temperature gradient which is hardly picked up by the grid are clearly visible. The arrangement was such that the field of the undisturbed liquid appeared dark on the photographs. The dark vertical band which intersects the isolines of the temperature field is the shadow of the plumb bob (normal to the plane of the plate).

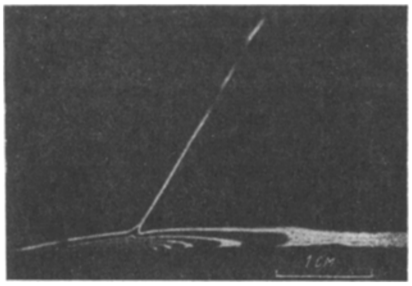

Fig. 2

The temperature field shown in the photographs is stationary in a coordinate system which moves with the velocity of the source. The beginning of the stationary state can be recognized from identical temperature-field patterns on two successive photographs made at 30-sec interval. Moreover, the beginning of the stationary state can be verified in the plate from the constancy of the temperature field (in the moving coordinate system). This was measured with thermocouples and recorded on the chart of a multichannel EPP-09 recorder. In the experiments with a plate of 1Cr13 steel in contact with water, the time to the beginning of this "quasi-stationary" state did not exceed two minutes from the time at which the moving heat source began to be effective.

The methods available for quantitative assessment of schlieren photographs provide for gradient measurements only in two-dimensional schlierens. A moving point source creates, in essence, a three-dimensional schlieren which cannot be calculated, as is generally agreed [5-7].*

It was found in the inspection of the moving temperature field near the inclined plane that the angle ($\beta$) of inclination of the flare relative to the plate (at the point at which the flare leaves the thermal boundary layer) depends substantially on the angle $\varphi$ under which the plate is inclined relative to the horizontal. An inclination of the plate is obtained by rotating the tray around the optical axis of the setup. Figure 3 shows schlieren photographs of the temperature field near an inclined plate in water and displays the temperature field for various angles $\varphi$. The source power was 7.33 W and the speed of the source 0.96 mm/sec (a) $\varphi = 16°$, The source moves downward and to the left; b) $\varphi = 53°$, source at rest; c) $\varphi = 53°$, the source moves upward and to the right; d) $\varphi = 90°$, the source moves upward). The angle $\beta$ decreases when the angle $\varphi$ increases; the point at which the flare leaves the boundary layer is shifted upward along the plate.

In Fig. 3d, which shows the temperature field at a vertical plate ($\varphi = 90°$), the exit point of the flare could not be observed (the diameter of the view field of the optical system is 10 cm). The setup was modified so that the field of the undisturbed liquid appears bright on

*It is suggested to calculate the gradients of temperature and heat dissipation for a two-dimensional temperature field created by a moving linear heat source.

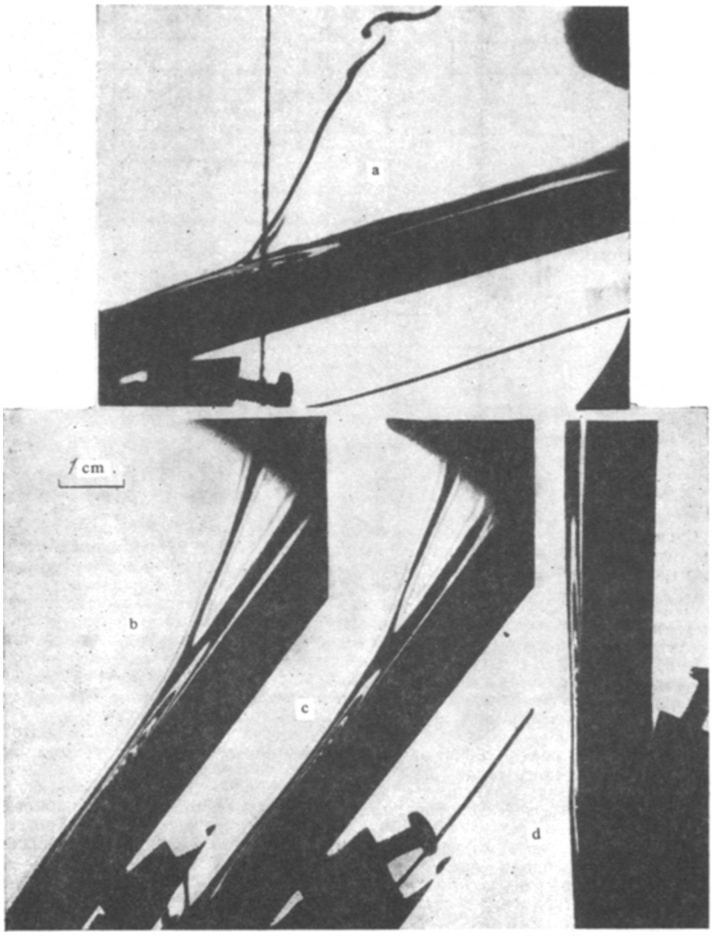


Fig. 3

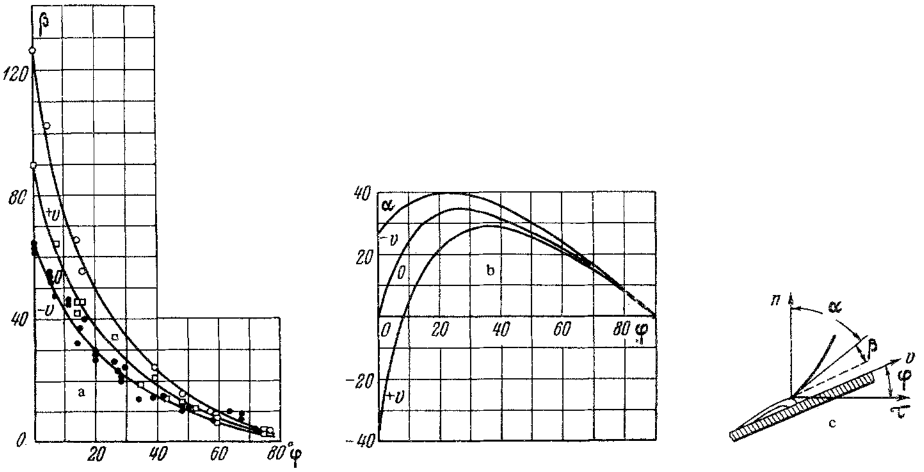


Fig. 4

the photograph (Fig. 3). The left side of the photograph shows a vertical dark line which is the shadow of the plumb bob.

Figure 4 displays the relation between the inclination of the flare and the angle of the plate relative to the horizontal: a) relation between the angles β and φ; b) relation between the angles α and φ; in the case of the curve +v, the source moves upward along the plate; in the case of the curve 0, the source is at rest; and in the case of the curve −v, the source moves downward along the plate. Figure 4c indicates how the angles are reckoned. The power was 7.33 W, and the speed 0.96 mm/sec). The measurements were made for velocities v of the source of 0 and ±0.96 mm/sec; the source power was 7.33 W. Interestingly enough, at angles φ on the order of 45–50°, the influence of the source-displacement speed on the orientation of the flare is greatly reduced, whereas at angles φ of about 70–75°, the orientation of the flare near the plate no longer depends on the velocity v, but is entirely determined by the inclination φ of the plate. Similar results were obtained for other source powers ranging from 4.0 to 7.5 W, and with source-displacement speeds of 0 and ±2.4 mm/sec. The curves of Fig. 4b were derived from the experimental points of Fig. 4a and transferred to the coordinates α and φ, with φ denoting the angle by which the flare deviates from the vertical at the point where it leaves the boundary layer at the plate.

The important role of the inclination of the plate for the flare orientation at large φ values is more clearly noticeable in this case. This is caused by the interaction between the flare and the convective boundary layer at the nonuniformly heated plate, with the importance of this interaction increasing with increasing angle φ.

REFERENCES

1. R. E. Bland and T. J. Pelick, "The Schlieren method applied to flow visualisation in a water tunnel," Paper. Amer. Soc. Mech. Engrs., WA-47, 1961.

2. O. A. Saudners, M. Fishenden, and H. D. Manshion, "Some measurements of convection by an optical method," Engeneering, vol. 139, 1935.

3. G. A. Ostroumov, Free Convection as an Internal Problem, Gostekhizdat, 1952.

4. Yu. N. Lyakhov, "The temperature field generated in a plate by a moving heat source," Sb. nauchn. tr., Permskii politekhn. in-ta, no. 21, 1965.

5. A. Ferry, Aerodynamics of Supersonic Flow [Russian translation], Gostekhizdat, 1952.

6. S. G. Popov, Measurement of Air Currents [in Russian], Gostekhizdat, 1947.

7. Physical Measurements in Gas Dynamics and Combustion, London, 1955.

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