SOME TEMPERATURE DISTRIBUTION RELATIONS FOR CONFINED SPACES WITH INTERNAL HEAT SOURCES

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Results are given for an interferometric investigation of the temperature fields in a two-dimensional confined space with natural convection. Relations are obtained for the distribution of air temperature over model height, taking into account the power of the internal heat sources.

The extremely complex processes of natural convection in limited spaces have not been studied sufficiently. As a rule, papers on the subject [1-5] have dealt with large volumes, the dimensions of the heat sources being incommensurably small compared with the rooms themselves.

We have conducted a special experimental investigation on an air model, with the object of adding to the experimental data on heat transfer in small finite volumes.

In view of the complexity of methods employing thermocouples and special thermal probes, we used an optical method of investigation. The experiments were carried out with an IZK-454 interferometer. The special features of the instrument affected the construction and dimensions of the model.

One of the principal planes of the experimental model, in which all the elements affecting thermal conditions were present, was chosen for observation. A linear model scale of 1:10 was adopted, in view of the diameter of the interferometer field (230 ± 5 mm), so that the whole field could be examined and photographed at once. The "depth of the model," i.e., its dimension in the direction of the light rays, was determined by the accuracy of the experiment (0.3 to 0.5°C). The internal arrangement of the model was similar to that of a natural object. Heat transfer conditions along the walls of the model were simulated by a special water jacket connected to a thermostat. Provision was made for mounting moveable electric heaters inside the model. The heaters had various shapes and sizes and could be mounted at various locations within the test volume and at any height.

The apparatus had measuring instruments for controlling the electric power fed to the heaters and also their surface temperature. The temperature of the inside walls of the model was measured by means of four thermocouple beads. The fixed thermocouples were all used for control purposes, while the field temperatures were determined from the interferograms.

A first series of experiments was performed to make an overall evaluation of the nature of the temperature field due to internal convective heat sources alone. The thermal zones due to natural convective currents in the test volume were studied for various arrangements and numbers of heating elements operated at various power levels.

Reference has been made [1, 2, etc.] to the phenomenon of "thermal overlap" in natural convection in confined spaces. In this case the question of the location of the plane of separation of thermal zones does not have a unique explanation. Our experimental investigations have convincingly confirmed the fact that the air in a confined space separates into thermal zones under the action of internal heat sources. Our results indicate that the interface between thermal zones most frequently coincides with the axis of symmetry of the thermal source (Fig. 1, a, b, c).

Three thermal zones may be distinguished in conformity with the quantitative change in temperature gradients (Fig. 1): first, a zone of strong natural convection, characterized by considerable temperature gradients dT/dh (for example, in a length equal to the source radius, the change may be as much as 16°C); secondly, a transition zone or a zone with weak natural convection, characterized by small temperature gradients (not more than 1.5°C in the same length); thirdly, a zone of practically motionless air.

The results were obtained for a constant heat flux through the model walls; air flowed in and out through the open ends of the model. The resulting nonuniformity in the heating of the air along the heat source did not exceed 1°C for t_s = 50 to 60°C, reaching 6°C for $t_s > 100$°C.

Temperature Distribution Over Height of Model

The interferograms obtained and the method developed for interpreting them [6] enable us to find the numerical value of the air temperature at any point in the model space. It was, nevertheless, convenient to choose certain characteristic sections (Fig. 1), with a view to comparing the various regimes and conditions of flow.

The nature of the temperature variation over section B is shown in Fig. 2. This result agrees with the investigations of other authors. A gradual increase in temperature, $dT/dh > 0$, is observed, beginning from the source level. With

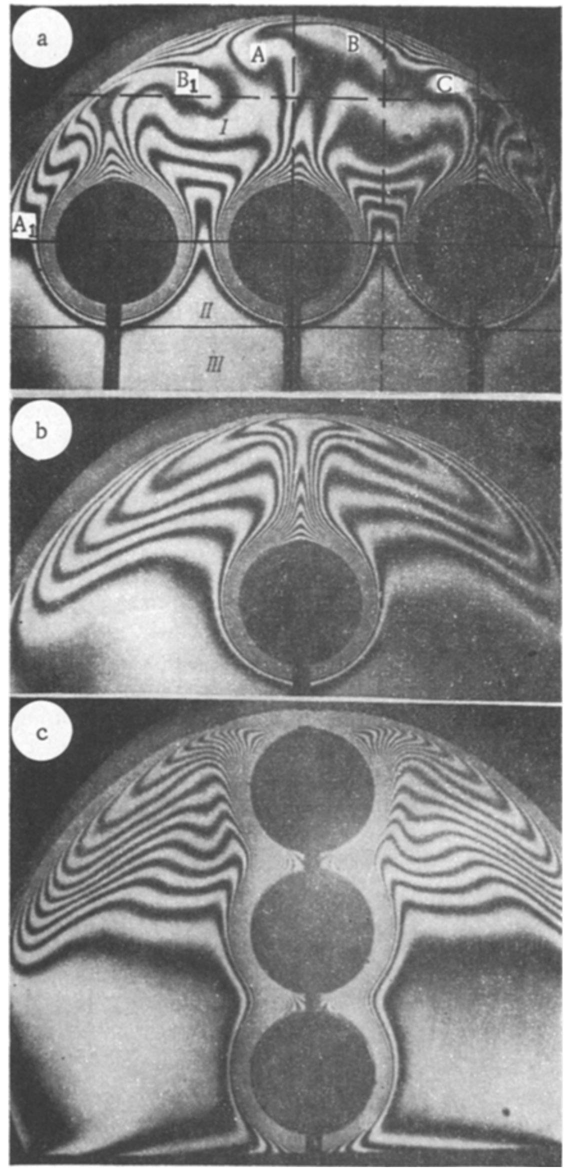

Fig. 1. Lines of equal temperature in the two-dimensional field of the model:
a – With three horizontally located heat sources and thermal power N = 20 w (I – zone of natural convection; II – transition zone; III – still air zone; A, B – vertical sections of maximum temperature gradients above central heat source $dT/dh \gtrless 0$ and between the heat sources $dT/dh \geq 0$; A_1, B_1 – horizontal sections passing through and above the heat sources); b – with one heat source (N = 7.5 w) located in the center section of the model; c – with three heat sources arranged vertically (N = 32.5 w).

a low heat source power, $dT/dh \cong 0$ and T = const. In section A (above the source) according to the results of other authors, a gradual drop in temperature should occur. In fact, in tests conducted at certain values of the heating element power in small limited volumes, an increase in temperature was observed. This phenomenon, called "temperature inversion," requires further study.

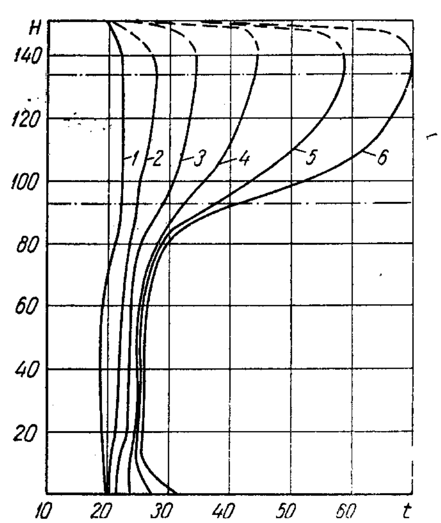

Fig. 2. Experimental curves of T = f(h) at section B (Fig. 1):
1 – N = 5 watts; 2 – 10; 3 – 20; 4 – 40; 5 – 80; 6 – 130.

It will be seen from the curves for section B_1 (Fig. 3) that the temperature gradients along the x axis are insignificant, and in the majority of sections (excluding the boundary layers) we may assume

$$\frac{\partial T}{\partial x} = \frac{\partial^2 T}{\partial x^2} \approx 0 \text{ and } T = \text{const}.$$

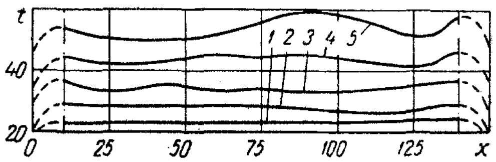

Fig. 3. Experimental curves of temperature variation over horizontal section B_1 (Fig. 1): 1 – 5 – see Fig. 2.

In order to permit extension of the results of a single test to the whole class of similar phenomena and transfer from the model to full scale, all the experimental results have been reduced to relative coordinates and are presented in the form of the criterial equation

$$\theta = \psi (\mathrm{Gr\, Pr})^c \eta^n \zeta^m. \quad (1)$$

The processes of natural convection observed in the experiments involved air flow at numerical values of the Grashof-Prandtl number in excess of $3.84 \cdot 10^7$.

The test data obtained show that, from the value 10^8 onwards, the (GrPr) number has no real influence on the relative temperature θ; the region of self-similarity has been reached.

According to the reduced experimental results for one of the variants studied (Fig. 1a), the exponent m has a mean value of 1/3. The experimental relations

$$\theta = A \zeta^m \eta^n, \quad (2)$$

plotted in logarithmic coordinates give the following numerical values of the coefficients:

$$A = 0.45 \text{ and } n = 0.5.$$

NOTATION

T_i, T_s, T_W – temperature of air at investigated point of model, surface of heat source, and inside face of wall; h_i, h_s, H_M – height of investigated point, distance from floor to axis of symmetry of source, height of model; N_i, N_{max} – heat source power for intermediate regime and for maximum heat load; $\theta = (T_i - T_W)/(T_s - T_W)$ – relative air temperature; $\eta = (h_i - h_s)/(H_M - h_s)$ – relative height; $\zeta = N_i/N_{max}$ – relative source power; $Gr = \beta(gl^3/\nu^2)\Delta T$ – Grashof number; $Pr = 0.72$ – Prandtl number; A, m, n – coefficients determined experimentally.

REFERENCES

1. E. V. Kudryavtsev, Modeling of Ventilating Systems [in Russian], Stroiizdat, 1950.
2. V. V. Baturin and N. V. Akinichev, In: Collected Scientific Papers of the Labor Protection Institutes VTsSPS, no. 2, 1959.
3. I. A. Shepelev, Turbulent Convective Streams Above a Heat Source, Izv. AN SSSR, OTN, Mekhanika i mashinostroenie, no. 4, 1961.
4. I. A. Shepelev, Vodosnabzhenie i sanitarnaya tekhnika, no. 1, 1962.
5. L. B. Chernin, Vodosnabzhenie i sanitarnaya tekhnika, no. 10, 1963.
6. V. V. Malozemov and I. A. Turchin, IFZh, no. 2, 1965.

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