STRUCTURE OF FREE CONVECTIVE FLOW IN A CLOSED THREE-DIMENSIONAL CAVITY

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Results are presented which were obtained from visual studies of free convective motion in a closed three-dimensional cavity formed by a rectangular housing and a heater located centrally inside the housing.

A study of the qualitative aspect of free convective heat transfer is of great interest since the nature of the motion produced basically determines heat-transfer conditions. The various methods for studying the structure of convective currents are well known [1-9]. Visualization of the motion by means of tobacco smoke [6-9], which makes it possible to study the qualitative picture of phenomena of arbitrary complexity, is widely used in experimental techniques. This method was selected for visual observations of convection in a closed three-dimensional cavity.

The test cavity (Fig. 1) was bounded by a transparent housing in the shape of a parallelepiped and by a heater centrally located inside the housing. The heating elements, which were installed in turn within the housings, differed in shape (cylindrical or hemispherical) and dimensions. Each heater consisted of a thin-walled brass casing 2 within which there was an asbestos cement core 3 reproducing its shape. The nichrome spiral 4 was mounted on the core. The heater was installed on a thermally insulating base consisting of the layer of asbestos cement 5 (δ = 8 mm) and the layer of foam plastic 6 (δ = 30 mm). Current-carrying wires passed through openings in the base. The heating element was covered with black paint. The thin coating of paint provided a satisfactory seal at the junction between heater and base. The heat-emitting element was covered from above by the transparent housing 1. The housings, which had a square base, were assembled from plastic 5 mm thick. Housings were tested for tightness and strength before installation on the models. Three openings were cut in each housing for the introduction of smoke: (a) in one of the upper corners; (b) in an edge of the parallelepiped; (c) at the bottom of a lateral surface. During an experiment one of the openings was used and the others were sealed with plasticine. The joint between the housing and base was sealed with plasticine in order to provide a hermetic seal for the test cavity. Heaters and housing of various sizes were prepared for the visual observations. In the experiments they were used in the combinations as shown in Table 1.

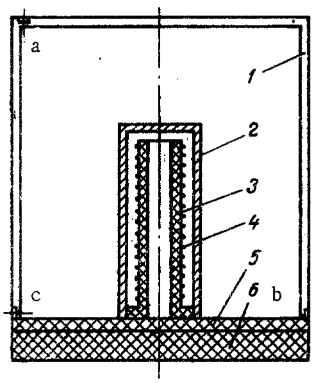

Fig. 1. Diagram of test cavity and heater.

The heater was supplied with rectified current from a stabilized source. The power supplied to a heater was monitored during an experiment.

TABLE 1

Heater, d × H	Cylindrical					Hemispherical
	34,3×110	72×35	52×35	42×72	52×60	R=43,5
Housing, $d\times h$	125×200	250×135	170×178	170×178	170×178	170×178

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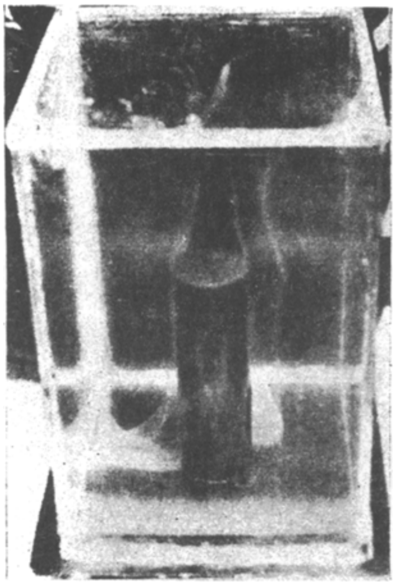

Fig. 2. Heater, 72 × 35; housing, 250 × 135; power, 22 W.

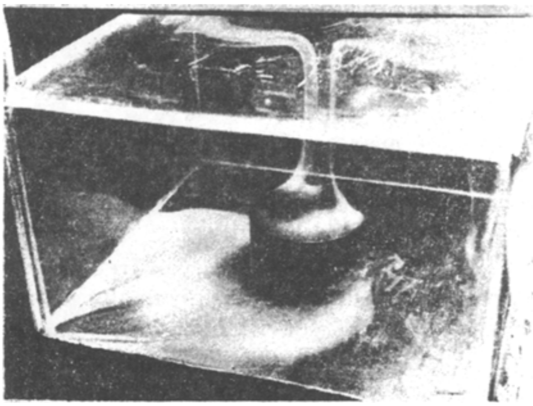

Fig. 3. Heater, 34.3 × 110; housing, 125 × 200; power, 22.5 W.

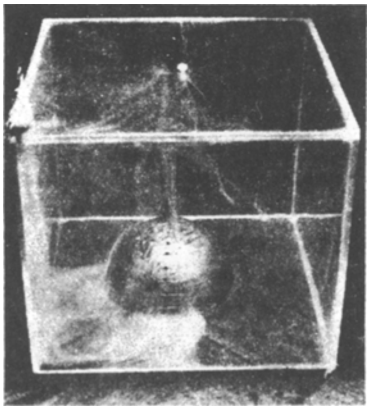

Fig. 4. Hemispherical heater; housing, 170 × 178; power, 18 W.

Before introducing tobacco smoke into the test cavity, the apparatus was heated for 6 h. From preliminary experiments with apparatus similar to that described above but fitted with thermocouples, this period of time corresponds to the establishment of steady-state conditions. Tobacco smoke was introduced by means of an aspirator. The aspirator made it possible to cool previously-collected smoke and to calibrate accurately the pressure at which the tobacco smoke was introduced into the test cavity. The observed convective flows were photographed with a Zenit camera having an Industar-51 objective fitted with adapter rings. To increase picture contrast, a bright light from a reflector was directed on the object from above and three lateral surfaces of the housing were blackened on the outside. The radiation–absorption properties of the system were not changed because the surrounding space is black by virtue of the ratio of dimensions (body within a body). Figures 2-4 show typical pictures of the process. In the test cavity symmetry of boundary conditions insures symmetry of motion. The entire cavity can be divided into four regions in which the nature of the flow is the same. The circulation contour is clearly seen. Heated air rises along the hot lateral surface of the heater, flows over its end face, moves away from the heater and toward the housing. Moving along the housing, the air is cooled, flows downward along the lateral surfaces, and moves toward the heat-emitting element. However, the structure of the convective flow which develops is much more complicated than simple motion along a circulation contour. The complexity of the cavity geometry leads to the creation of effects not observed previously in a plane layer. In addition to the main circulation contour there is motion directed from the symmetry axes toward the diagonals in the upper plane and from the diagonals to the symmetry axes in the lower plane. Under the effect of these currents, streamers from the main circulation contour acquire varied characteristics. A descending current streamer on reaching the lower base is directed not toward the heater immediately but is deflected along the wall to a region separated from the heater by a minimum distance. It would appear as if the streamers are pushed off toward the symmetry axes and several regions of retardation appear along the diagonal in the form of an extended lobe. In the upper plane the streamers undergo oscillatory motion between the diagonals. As a result, in order to maintain continuity, the streamers do not descend linearly along the lateral surfaces but undergo wave motion in the plane of the wall. Features such as "lobes" and oscillatory and wave motion were observed in all cases studied; consequently, the conditions for the creation of this general picture are produced by the rectangular housing and do not depend on the shape and size of the heater.

The nature of free convective flow changes insignificantly as a function of the ratio between heater and housing dimensions. For tall heaters in a narrow cavity, persistence of the smoke stream is absent in the central portion of the circulation contour. Motion of the air is confined to the regions near the walls. In experiments with low heating elements, features such as secondary flows and vertical layering were observed. In the center of the minimum cavity cross section between housing and heater, a rising flow was observed from both sides of which closed vortices originated.

Thus the structure of convective flow in a closed region is mainly determined by its configuration. The more complex the geometry of the cavity, the more complex is the nature of the resulting motion. For plane layers, convection may be represented by motion along a circulation contour. In a three-dimensional cavity supplementary currents are observed in addition to the main circulation contour. Since the conditions for heat transfer are basically determined by the nature of the motion produced, one should expect different quantitative relations for a three-dimensional cavity.

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