A SHIELD FOR PROTECTING DETECTORS FROM MECHANICAL IMPURITIES IN A GAS STREAM

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Apparatus containing electric-arc heaters, in which the gas stream is contaminated with mechanical impurities produced by erosion of the material of the electrodes, the nozzle, and other structural elements, have now obtained wide distribution.

In many cases the presence of impurities in the stream is an undesirable phenomenon. For example, it eliminates the possibility of using in these apparatus the measurement methods based on the recording of processes at the surface of a measuring element. This includes the method of catalytic detectors, used to study the departure of the state of the gas in a stream from thermodynamic equilibrium and to study the catalytic properties of surfaces. In apparatus containing electric-arc heaters the probability of a departure of the state of the gas from equilibrium is high owing to inelastic collisions between electrons and gas particles, as well as because of the freezing in of the state of the gas during its expansion in the nozzle.

To eliminate the influence of mechanical impurities on the test surface it is desirable to employ separation of the particles using special shields, the operation of which is based on the inertia of the particle motion. The flow behind the shield must satisfy the following requirements: to be free of impurities, to have a region of undisturbed gasdynamic flow of sufficient size, and to be well controlled by calculating or experimental methods. Prandtl–Meyer flow can be chosen as such flow.

In this case the flow near a shield in the form of an angle is not two-dimensional. It is considerably distorted by the return flow of gas from the downwind side of the shield, which leads to the formation of vortex systems with their subsequent interaction with the oncoming gas stream. Calculation of the total flow pattern with allowance for three-dimensional effects is very difficult. Special attention is therefore paid to an experimental investigation of the flow over shields using methods which permit one to visualize the three-dimensional flow pattern and to estimate the dimensions of the regions in which Prandtl–Meyer flow is realized.

Diagrams of the structural solutions for the shields are presented in Fig. 1, where 1 and 2 are the holder and 3 and 4 are the elements of the shield, which consists of one or two plates. When there are two plates, one of them is oriented in the direction of the stream, while the other is placed at an angle to it.

The dimensions and arrangement of the shield components are chosen from the condition of realization of the calculated flow behind the shield, the absence of blocking of the wind tunnel, the value of the Mach number M of the stream, the requirements for the size of the zone free of impurities, and the condition of the absence of gas condensation in the expanded stream; in accordance with this a shield was built for which the angle of inclination of the plate to the direction of the stream was 30°, while the width of the plate was 60 mm. An experimental investigation of the pattern of flow over such a shield was conducted at $M = 1.5$ and 3.0 in a wind tunnel with a closed working section formed by interchangeable plane nozzles and instruments for visualization of the flow [1]. Here the density of the air stream was kept equal to $\rho = 0.15$ kg/m^3. The investigations were conducted with different distances of the detector from the surface of the inclined surface of the shield ($h = 8$, 22 mm) and different distances of the end of the detector from the apex of the deflection angle of the stream ($x = 30$, 35, 40, 45, and 50 mm). The flow was visualized by means of shadow photography, a vapor screen [2], and an oil film. A TE-14 Töpler instrument was used in the shadow photography. In the visualization by means of a vapor screen a mixture of distilled water and alcohol was supplied at a pressure of 2.5 atm to two atomizers equipped with expanding nozzles with a diameter $d = 1.5$ mm and located in the forechamber of the tunnel.

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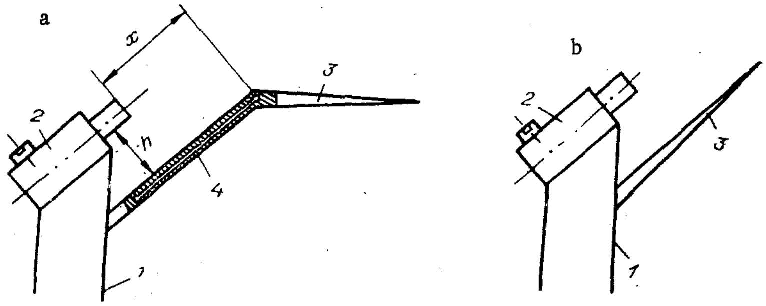

Fig. 1

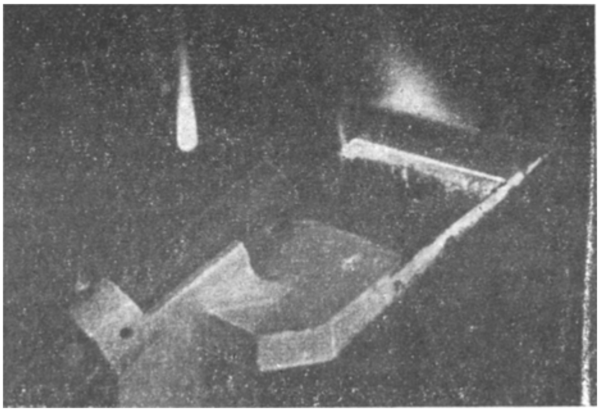

Fig. 2

Particles of finely dispersed mist were formed in the stream as a result. The flow region being visualized was illuminated from an intense light source through a slit diaphragm. The presence of aerodynamic inhomogeneities led to redistribution of the particle concentration and of the intensity of the reflected light and was recorded photographically. The flow pattern in the boundary layer was also recorded photographically using an oil film.

The experiments on testing the workability of the proposed shield under conditions when the air stream is contaminated with mechanical impurities were conducted in a wind tunnel with an electric-arc gas heater under the following conditions: Air pressure in the forechamber $p_0 = 14 \cdot 10^5$ Pa; stagnation temperature $T_0 = 3500$–4000°K; current and voltage of heater arc $I = 900$ A and $U = 500$ V, respectively; the air was accelerated in a conical copper nozzle having a critical cross section with a diameter $d^* = 5$ mm and an exit diameter $d_e = 100$ mm. The degree of contamination of the detector surface in the absence and in the presence of a shield was determined from the change in the electrical conductivity of the surface.

The distribution of the mechanical impurity for flow over a shield in the form of a plate at an angle of attack is shown in Fig. 2 ($M = 1.5$). The cross section standing off 15 mm from the tip of the shield is visualized in the experiment to which Fig. 2 refers. The region of the highest concentration of impurity particles looks bright in the photograph. It is seen that impurity particles do not penetrate into the region shaded by the shield. The investigations showed that appreciable penetration of impurity particles into the shaded zone starts with a distance $x \simeq 30$ mm.

Figure 3 shows the pattern of flow over a shield in the form of inclined plates under the following conditions: $M = 1.5$, $x = 45$ mm, and $h = 22$ mm; the following zones are denoted: 1) compression shock; 2, 3) fan of rarefaction waves; 4) bow shock wave; 5, 6) zones of reduced density. The position of the fan of rarefaction waves was calculated in accordance with [3]. According to the experimental results, the zone of free flow of mechanical impurities behind the shield has an aperture angle of ~22°. This result agrees with the calculated value.

The vortex zones connected with the return flow of air from the high-pressure region below the inclined plate into the low-pressure region above it are shown in Fig. 4 ($M = 1.5$, $x = 45$ mm, and $h = 8$ mm); it is seen that under the test conditions the vortices occupy the boundary regions of the inclined surface, while the central zone (~30 mm) is free of vortices.

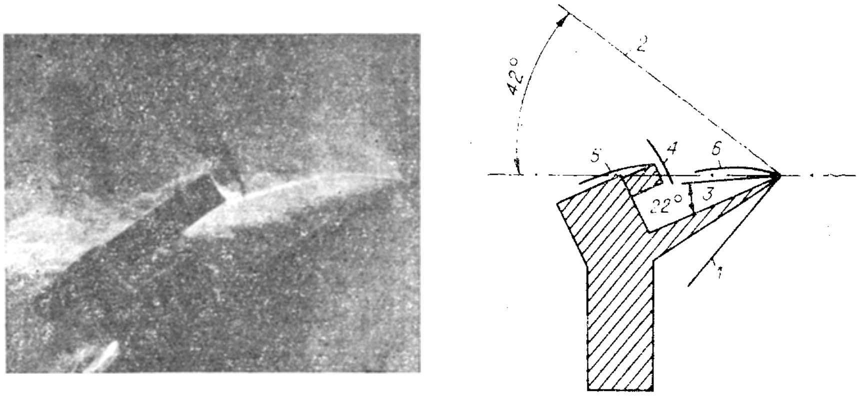

Fig. 3

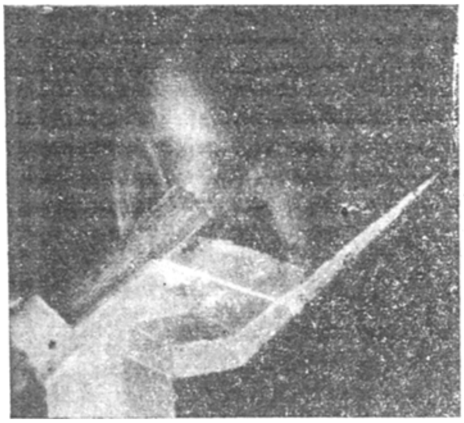

Fig. 4

Fig. 5

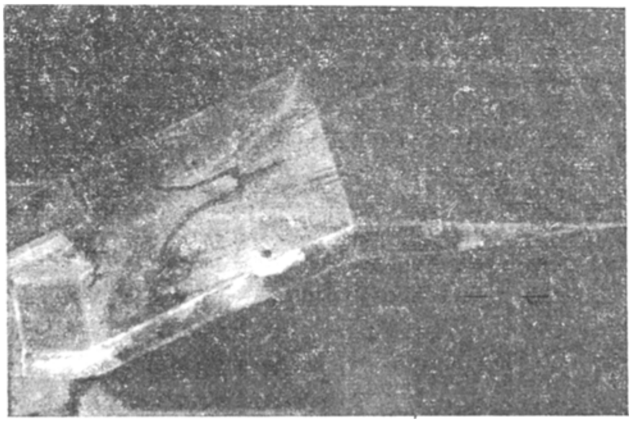

Fig. 6

The pattern of flow over a detector with a shield at M = 3 is presented in Fig. 5, while the pattern of flow in the boundary layer in this case is presented in Fig. 6. The size of the zone in which Prandtl–Meyer flow is realized can be determined from Fig. 5; the sector comprises ~10°. This result agrees with the calculated value.

Separation of the boundary layer at the surface of the shield was observed in some experiments. The use of a special device to suck off the boundary layer (see Fig. 1a) helped to get rid of the undesirable effect. The device has the form of a chamber connecting the zone of separation of the layer with the zone of reduced pressure. The experiments showed that separation of the boundary layer is delayed when such a device is used and a zone with the calculated flow, whose size is sufficient for the mounting of a detector, forms behind the apex of stream deflection.

The shields were used to protect the surfaces of catalytically active detectors (the detector surface was coated with silver, for example) in an apparatus with an electric-arc air heater. It should be noted that at $M \approx 6$, attainable on this apparatus, the zone with Prandtl–Meyer flow comprises 5-7° (if one assumes, by analogy with the results at lower M, that the results of the experiments and calculations will also agree in this case).

The experiments demonstrated the workability of the proposed shields. In the absence of a shield the state of the detector surface varied in the course of one startup ($\tau \approx 10$ sec) — the surface became electrically nonconducting. When shielded, the detector surface became electrically nonconducting after four to five 10-sec startups. Heat-flux measurements with shielded catalytic detectors showed that under the test conditions the heat flux did not depend on the catalytic activity of the surface with the accuracy of the error in the heat-flux measurement. Thus, these experiments made it possible to reveal the character of the flow over shields whose action is based on the use of stream deflection with the realization of Prandtl–Meyer flow and to decrease the deposit of impurities on the detector surface in an apparatus with an electric-arc gas heater.

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BREAKUP OF A LIQUID DROP AGGREGATE IN SHOCK WAVES

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The development of investigations of the dynamics of multiphase flows indicates that the breakup process of a liquid drop has a significant effect on the physical and chemical phenomena in a gas–liquid medium. However, the majority of the available data concerning the breakup of a drop have been obtained by using as an example individual drops or drops remotely spaced from one another [1, 2]. In actual cases, an aggregation of drops in a system is distributed in a random way. As a result, there are still no grounds for assuming that the behavior of the whole aggregate is identical with the behavior of drops taken individually from this aggregate. It is justifiable to expect that for a certain density of the number of drops, a mutual effect of the drops on one another will start. In the modern power installations, using the energy of liquid fuel, the density of the number of drops per unit volume is large and increases with increase of the pressure at which combustion of the fuel occurs. An increase of the volume fraction of liquid in the system up to values exceeding 1% of the gas volume may require the interaction between adjacent drops to be taken into consideration as the distance between drops decreases to a value of $\Delta l < 10d_0$, where d_0 is the size of the drop. The appearance of specific breakup properties of the drops in the presence of closely arranged adjacent particles is entirely probable.

One of the causes of the mutual effect of the particles is shown in [3], where a hypothesis is expressed concerning the increase of the speed of breakup in a chain of consecutive drops in consequence of the increase of the two-phase flow density because of the collapse of particles which are higher with respect to the flow than the original. However, this conclusion from [3] is debatable, since it is drawn only on the basis of analysis of the final stage of breakup, when screening of adjacent particles during blowing with gas is not taken into account. The experimental demonstrations of the acceleration of breakup given are not sufficiently convincing.

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