The dependences of the coefficient of total resistance C_x of the sphere and of the resistance C_F due to the presence of viscosity are shown in Fig. 5. The total resistance and the frictional resistance decrease with cooling of the surface of the sphere.

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STRUCTURE OF A MULTICOMPONENT BOUNDARY LAYER IN MODELS UNDERGOING BREAKDOWN

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UDC 532.526

§1. Experiments were carried out in a high-temperature gasdynamic apparatus, using an inductive high-frequency discharge in an air flow as the gas heater [1]. The arrangement of the apparatus is illustrated in Fig. 1, where 1 is a radio-frequency generator, 2 is the test chamber separating the discharge channel and heating inductor 3 from the surrounding atmosphere, 4 is a two-component locator, 5 is the test model, 6 is the extraction tube (exhaust pipe), 7 is a centrifugal blower with a rate of delivery capable of smooth variation, 8 is a set of flowmeters in the gas-supply tract, 9 is a screw-type air compressor, and 10 is a set of inert-gas cylinders. The apparatus was usually operated in air from a compressor creating an excess pressure of 0.25 atm. In order to facilitate the starting of the apparatus, argon was employed, the system being connected to gas cylinders. As source of electrical energy for the inductive discharge, a radio-frequency tube generator operating at a frequency of 17 MHz was used. The maximum oscillatory power consumed was 50 kW. The cylindrical discharge channel comprised a quartz tube carrying a double-wound copper solenoid, playing the part of inductor and heating element.

The flow of gas passed into the discharge channel from a preliminary chamber, in which it was given a spiral—translational motion. The preliminary chamber contained a profiled annular space to which the gas was fed tangentially. Depending on the swirling intensity of the incident gas, three gasdynamic modes of discharge initiation were encountered. The best situation was that in which the discharge region was filled with hot gas, the discharge ignited from the wall, and the process continued for an unlimited time. For weak swirling of the gas, the discharge sticks to the walls, and this leads to thermal decomposition of the quartz; for intense swirling the discharge is drawn upward along the flow and is ultimately blown away by flows of cold gas. The results described in this paper were obtained under optimum gasdynamic discharge conditions. A characteristic feature of the process lies in the fact that the lateral leading edge of the discharge is inclined to the incident flow in such a way that the cold gas passes into the "flame" along the normal at a rate of ~10 cm/sec and on being heated is accelerated to a velocity of ~30 m/sec in the axial direction.

It is well known that the mechanism for producing inductive plasma involves the existence of induced voltage pulses, which may be the reason for the appearance of pulsations in the plasma. Special experiments showed that the time interval between the voltage pulses ($t \sim 10^{-8}$ sec) was several orders of magnitude shorter than the plasma attenuation time ($t \sim 10^{-1}$ sec). An analysis of high-speed motion pictures indicated the absence of intensity pul-

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sations, i.e., under the conditions of the experiments in question the pulsating character of the current in the inductor had no effect on the temperature (thermal) uniformity of the flow. The radial temperature distribution at the cut-off point of the discharge channel, shown as curve 1 in Fig. 2, indicates the existence of a fairly extended constant-temperature core or nucleus in the central region. The axial temperature dependence down the flow (curve 2 of Fig. 2) is typical of laminar flow.

The temperature dependences shown in Fig. 2 are the result of the averaging of different temperatures measured by reference to the emission of the excited atomic lines of oxygen and nitrogen and the branched systems of molecular nitrogen bands over a wide spectral range (0.22-0.96 μ). Thus, on the axis of the jet, in the working part of the flow corresponding to the cut-off point of the quartz tube, the temperature of the heated air was 8500°K; the pressure 1 kg/cm^2; the electron density $3 \cdot 10^{15}$ cm^{-3}; the total thermal flux to the unbroken cold model 0.4 kW/cm^2; and the radiative component 0.1 kW/cm^2. The test models were placed on a two-component locator enabling them to be moved in the axial and radial directions inside the jet.

§2. During the flow of a high-temperature gas stream 1 (Fig. 3) around an asbestos plastic model 4, a boundary layer 2 comprising vapor from the material itself, components of the hot air, and the products of interactions between these develops on the surface undergoing breakdown. The chief aim of our investigation was to study the composition of the main components of the vapor on passing across the boundary layer. In the experiments we used models having the form of a flat plate 3 cm wide, 3.5 cm long, with a cylindrical head section 1.5 cm in radius. The models were fixed in a water-cooled holder 3 placed on the locator. The existence of the constant-temperature profile 1 (Fig. 2) in the gas flow and the use of a plane model enabled us to create almost one-dimensional conditions along the generator of the cylindrical surface of the head part of the model in the boundary layer.

§3. In order to study the composition of the boundary layer, we chose the method of emission spectral analysis. The optical system for measuring the emission from the boundary-layer vapor is illustrated in two projections in Fig. 3. The optical system (with a magnification of unity) consisted of a standard objective 5 and a DFS-13 diffraction spectrograph 6 with a plane grating of 1200 lines/mm and a dispersion of 2 Å/mm. The working slit width was 30 μ. The model was focused on the slit 7 of the spectrograph so as to be able to record the radiation of the boundary layer, the model, and the plasma at the same time. Calibration was effected by means of a standard SI-8-200U lamp. For photometric purposes we used an IFO-451 recording microphotometer. The photometric density of the film was converted into intensity by the method of heterochromic photometry. The geometrical length of the emitting boundary layer along the line of observation was determined from motion pictures recorded with a KSK-1 camera 8.

The intensity of the spectral lines is the most natural spectral characteristic for revealing the quantitative content of any element in the boundary layer. As a result of various physicochemical processes, a concentration of excited atoms and ions defining the intensity of the emission from each line is established in the boundary layer. The intensity of the spectral line for an optically thin layer of gas of length l emitting into unit solid angle and existing in a state of thermodynamic equilibrium is determined by the expression

$$I = \frac{A_k^j}{4\pi} \frac{g_j}{g_0} N_0 \exp\left(-\frac{E_j}{kT}\right) h\nu l$$

(the generally accepted notation is employed in this equation). The quantities g_j, E_j, g_0, and A_k^j were taken from reference literature [2-4]. The absolute intensity of the lines is determined by the concentration of excited atoms N_j at the upper level. The more the test material is broken up (the degree of decomposition determining the total concentration of a particular element N_0) and the more energetically the excitation of the atoms takes place, the more of these excited atoms that occur.

In our calculations of the concentrations we used the temperature profile measured by the method of relative intensities, based on the molecular bands of CN [5] (Fig. 4). For these measurements it is vital to choose the analytical spectral lines correctly. The main criterion in selecting the lines was the composition of the original material, i.e., we determined the concentration of the elements composing the essential part of the asbestos plastic.

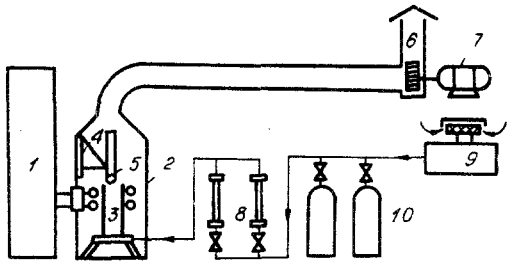

Fig. 1

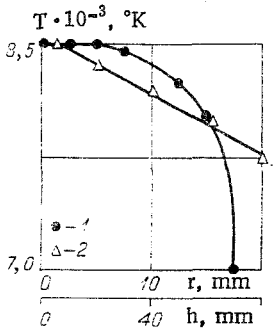

Fig. 2

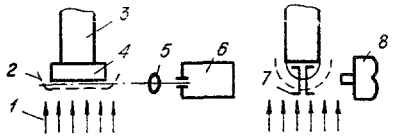

Fig. 3

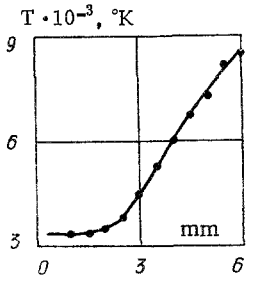

Fig. 4

From the point of view of spectral measurements we chose lines free from superposition and also from interference on the part of neighboring stronger lines. In order to reduce the influence of reabsorption we preferentially considered nonresonance lines with a minimum transition probability for elements having a substantial concentration in the initial state. In individual cases the influence of self-absorption was checked by reference to multiplet lines.

In addition to this, from the whole set of lines associated with a particular element we tended to consider those with an excitation energy of $E_j \leq 5$ eV so as to avoid the influence of the hotter side layer on emission along the line of observation. Initially we recorded the emission spectra of the vapor from the boundary layer of the decomposing asbestos plastic in the spectral range 0.2-0.9 μ. As the result of a careful analysis of the resultant spectra with due allowance for the foregoing considerations, we chose the following spectral lines, Å: Al I 3944, C I 2478, Ca I 6122, Ca II 3934, Fe I 4375, K I 7665, Mg I 4571, Mn I 4783, Na I 5890, and Si I 3905.

The results of our measurements of the concentration distributions of the main components across the boundary layer appear in Fig. 5, the molar proportion y_i of the component i being recorded along the vertical axis. Two characteristic zones appear in the boundary layer. The first zone, 2 mm in extent, lies close to the wall of the decomposing material and has a constant temperature. Here the concentration of the decomposition products varies very little. The second zone, lying in the high-temperature region, is associated with the lower limit of the boundary layer and is characterized by a sharp fall in the concentrations of all the components.

As regards the character of the change in vapor concentration across the boundary layer, the components may be subdivided into three groups.

The curves relating to the measurements of Ca, Na, and K, with an excitation potential of E_j ~ 2-4 eV, have a maximum value of the concentrations at the wall and fall sharply toward the outer boundary. The concentrations of Al, Fe, Mg, Si, and Mn atoms, with an excitation potential of E_j ~ 3-5 eV, have a maximum in the layer lying at a distance of ~1 mm from the wall. To this group we may also assign the radical CN, the properties of which were considered in more detail in [6]. The carbon concentration, measured by reference to the line C I 2478 Å with an excitation potential of 8 eV, has its maximum displaced in the high-temperature direction. The third group comprises the molecular components C_2, SiO, MgO, AlO, and CaO, the concentrations of which we were unable to measure owing to disruptions created by foreign lines in their rotational structure. However, it should be noted that the emission spectra of these compounds appears at the decomposing wall in layers ~0.5-2 mm thick, the maximum

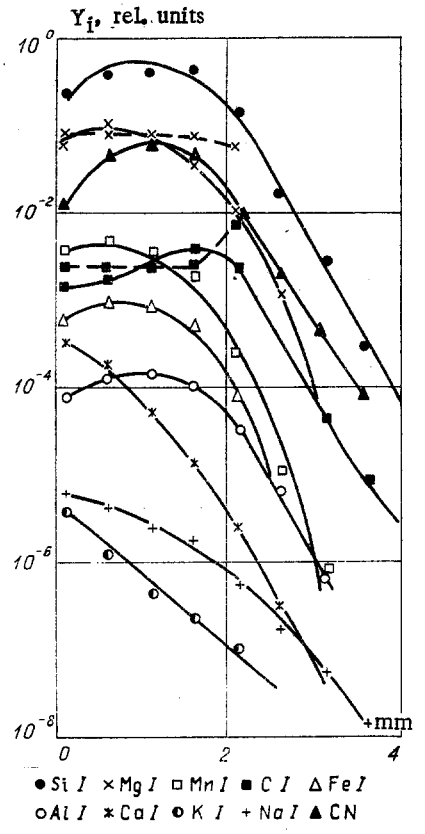

Fig. 5

emission intensity, and hence, the maximum concentration, lying at the inner limit of the boundary layer. It is reasonable to assume that these compounds are formed by the sublimation of the corresponding oxides formed by the melt of heated material. Thus, close to the wall the composition of the boundary layer is mainly determined by the decomposition products of the test substance.

The experimental data were compared with the calculated results illustrated as broken lines in Fig. 5 for the elements Mg and C. The calculation was carried out for an equilibrium chemically reacting system without allowing for the interaction of the original asbestos plastic material with the hot air. This comparison is only valid for the region close to the wall, consisting mainly of decomposition products of the material; Fig. 5 reveals excellent agreement with the calculated values in this region.

We may thus assert that the region of the thermal boundary layer close to the wall constitutes a promising object for studying spectral absorption coefficients, since the temperature, pressure, and chemical composition are sufficiently constant in this region.

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COLLAPSE OF A SPHERICAL CAVITY, INDUCED BY AN UNDERWATER SPARK, NEAR A SOLID WALL

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A knowledge of the laws of the physical processes accompanying the collapse of cavities, formed by an underwater spark, in the presence of asymmetric boundary conditions is very important for a proper understanding of the causes responsible for the phenomena. We know, for instance, that neglect of the flow energy in the dynamic calculation of structures for impact loading of the explosion type can lead in several cases to overestimation of the theoretical source energy by a factor of two [1, 2]. In addition, a clarification of this question will lead to improvement in the technology of electric pulse processes in water [3].

The few theoretical [4-9] and experimental [10-13] investigations of the effect of a solid wall on the collapse of a spherical cavity in a liquid medium indicate deformation of the cavity, the formation of a liquid jet in the direction of the wall at the concluding stage of collapse, and consequent damage to the wall under certain conditions [9-13]. The proximity of the wall is also the reason for the translational movement of the cavity or its center toward the wall.

In some theoretical studies [5, 6], spherical collapse of a cavity has been considered, and the quantitative characteristics of the process obtained for this case have been used in some calculations [14]. Kling et al. [13] made a thorough experimental investigation of the quantitative picture of the effect of an adjacent solid surface on the collapse of spark-induced bubbles, but their experiments were conducted in a flow of liquid, i.e., in the presence of another additional source of asymmetry — the slip of the bubble in the flow, which leads to a significant change in the nature of cavity collapse [4, 9, 15].

The aim of the present work was an experimental verification of the applicability of the available experimental models for a description of the dynamics of collapse of a spherical vapor—gas cavity (VGC), formed by an underwater spark, near a plane solid wall.

1. Description of Experimental Apparatus and Methods of Investigation. The experiments were conducted in a special tank (1500 × 1000 × 500 mm) filled with distilled water. The tank was furnished with two Plexiglas windows, which enabled us to photograph the process in transmitted light from a powerful source. The solid wall was a square Viniplast sheet 20 mm thick, whose linear dimensions exceeded the maximum cavity diameter by a factor of more than two. The wall surface was set perpendicular to the free surface of the liquid. The gas cavity was formed by an underwater spark produced by the discharge of a 1-μF capacitor bank across a 10-mm spark gap. The charging voltage was 25 kV and the circuit inductance was 3 μH. The stability of the discharge (and, accordingly, of the parameters of the induced bubble) was maintained by straightening of the spark channel with a Constantan wire (diameter 0.003 mm) and by natural degassing of the liquid. The electrodes consisted of two copper needles of diameter 4 mm. The discharge took place at a depth of 240 mm, so that even in the case of a bubble of maximum radius (53 mm) the free surface had no effect on its motion

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