DETERMINATION OF THE ELECTRON CONCENTRATION IN THE BOUNDARY LAYER OF A MIXTURE OF AIR AND THE DECOMPOSITION PRODUCTS OF AN ASBESTOS PLASTIC

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An experimental study has been made of the effect of the decomposition products of a material, blown into the boundary layer, on the electron concentration in a high-temperature stream of air. Investigations of the electron density are important for an understanding of the mechanism of the interaction between a high-temperature stream of air and a material and find application in applied problems [1].

1. An experimental dependence for the distribution of the electron density over the thickness of the boundary layer was obtained on the basis of measurement of the halfwidth of the spectral lines of neutral magnesium. A method proposed in [2] was used to determine the electron concentration. The small excitation potential of the spectral lines of magnesium makes it possible to measure the electron concentration in regions with a rather low temperature. The absence of magnesium in the oncoming flow permits obtaining undistorted profiles of the lines directly from the boundary layer. A study was made of the contours of the magnesium series Mg 1 4703 Å and Mg 1 4351 Å, corresponding to the transitions $5^1D_2 \rightarrow 3^1P_1$ and $6^1D_2 \rightarrow 3^1P_1$. Approximate calculations, carried out using the data of [3], show that the broadening of the above lines is due mainly to the quadratic Stark effect. The contribution of other mechanisms to the broadening does not exceed 10% and is not taken into account in what follows.

A jet unit was used to set up a flow of high-temperature air; as a gas heater (at a pressure of 1 atm) the unit used an inductive high-frequency discharge [4]. As a result, in the working part of the flow there was set up a steady-state plasma jet, whose flow velocity (in an upward direction) was 30 m/sec. The diameter of the jet was equal to 37 mm, while the temperature of the plasma attained 8500°K and varied in a radial direction by not more than 150-200°K. The electron concentration was 3×10^{15} cm^{-3}, and the thickness of the radiating layer was ~200 mm. The heat flux, measured with a calorimeter from a polished aluminum surface with a mirror finish, was 0.3 kW/cm^2. The water calorimeter was of cylindrical form with a flat end. The measurements were made to the end surface using a standard method.

Figure 1 shows a schematic diagram of the jet-type high-temperature unit 1 and the optical system in two projections, used to observe the boundary layer 2 at the decomposing model 3. The model was a

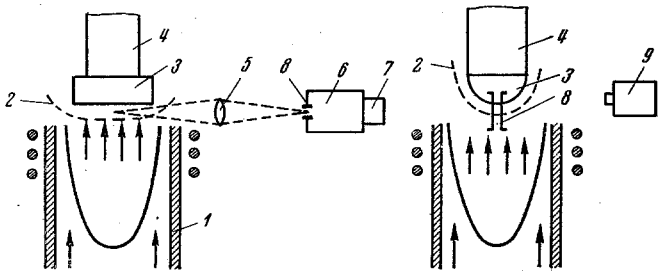

Fig. 1

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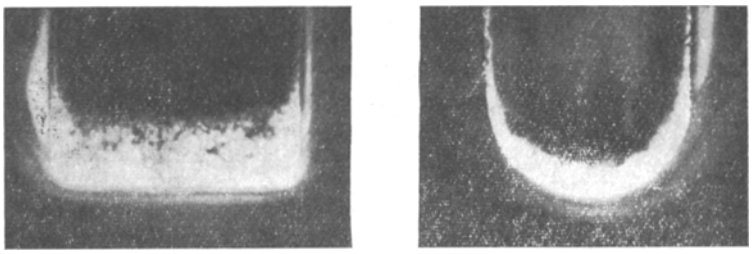

Fig. 2

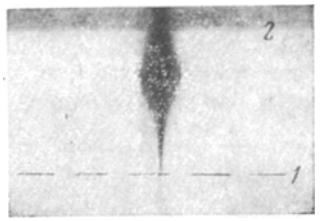

Fig. 3

flat plate with a width of 3 cm and a length of 3.5 cm, having a cylindrical head part. The radius of the head part was 1.5 cm. The chosen flat form of a model with a cylindrical head part made it possible to obtain a one-dimensional boundary layer in the cross section under investigation; this avoids laborious computations using the Abel inversion method. The model was mounted in a special water-cooled holder 4 and was introduced into the working part of the flow using a two-component positioner for a time equal to 0.1 sec.

The optical system, with a magnification equal to unity, consisted of a standard objective 5, and a DFS-13 diffraction spectrograph 6, in whose receiving section there was mounted the tape winder 7 from a Rodina moving-picture camera. The radiation, leaving a spectroscope with a resolution of 2 Å/mm in the first order of magnitude, was recorded on KN-4 film. The optical system was adjusted to the axis of symmetry of the model. On the slit 8 of the spectrograph, a projection of which is shown in Fig. 1, there were projected the images of the decomposing surface of the model, the boundary layer, and the oncoming flow. The linear entrainment of material and the forms of the sample and the boundary layer at the time of the experiment were monitored by a KSK-1 moving-picture camera, using colored glasses KS-14 and NS-8, and an infrared moving-picture film with a maximal sensitivity in the range of 0.75 μ. The frequency of the photography was 1 frame/sec, which made it possible to record the process in time. The exposure time was 0.5 sec. Figure 2 shows samples of the decomposing model and of the boundary layer in two projections.

An experimental check, made to determine the instrument effect, showed that its value does not exceed $\Delta\lambda \leq 0.007$ Å.

The intensity of the radiation of the whole optical system and its recording part was calibrated using a standard SI8-200 lamp. The thickness of the boundary layer was ~ 5 mm at the critical line of the model where the measurements were made. Figure 3 shows a typical sample of a spectrogram. Here the spectrum is well resolved over the thickness 1 of the boundary layer, and the boundary 2 of the surface of the model can be clearly seen.

Analysis of the spectrograms in an IFO-451 recording microphotometer was done by scanning of the spectrum with respect to the slit for different cross sections of the boundary layer. The optical system of the IFO-451 instrument ensured projection of the spectrum on the slit of the instrument with a 20-fold magnification. This permitted obtaining a spatial distribution of not less than 0.5 mm, which constitutes 0.1 of the thickness of a characteristic boundary layer.

2. To verify the absence of self-absorption at the lines under consideration, a series of tests was also made in which the longitudinal dimension of the model was varied by two times more than the change in the thickness of the radiating boundary layer. These tests showed that there was no self-absorption at the lines under investigation.

In addition, the optical system described above was used to carry out a series of experimental investigations to determine the space and time homogeneity of the electron density of an unperturbed flow in the working section. The measurements were made from the broadening of the H_α and H_β lines. The experiments established a sufficient degree of homogeneity in the distribution of the electron density along the flow.

After a test, three zones were observed in a sample: a coked zone, a pyrolysis zone, and a zone of the starting material. The shift of the surface of the pyrolysis zone was determined by cutting the sample in half into planes of symmetry, and by measuring the total thickness of the coked and pyrolysis zones

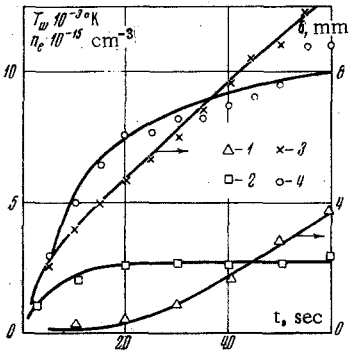

Fig. 4

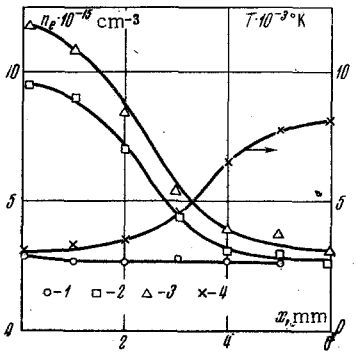

Fig. 5

using an instrumental microscope. We shall arbitrarily call this zone the decomposition zone. To obtain the time dependences, a series of experiments was made with different durations.

Figure 4 shows the linear entrainment of material 1, the temperature of the surface 2, and the shift of the internal decomposition boundary 3, as functions of time. These parameters characterize the process of decomposition for typical experimental conditions. After a certain transitional period, the rate of linear entrainment, the rate of shift of the internal decomposition boundary, and the temperature of the surface attain steady-state values. The rates of shift of the external surface of the material and of the internal decomposition surface are constant but not equal to each other; therefore, decomposition may be regarded as a quasi-steady-state process. We note that the lower limit of quasi-steady-state conditions is determined by the time required for the temperature of the surface to reach steady-state conditions. Experiments with a longer duration than those presented here differ by the presence of a second set of quasi-steady-state decomposition conditions. The material is completely coked and the decomposition corresponds to that of a model made of coke. These conditions were not investigated.

The electron concentration was determined using a well known formula [5] connecting the halfbreadth of the line, the electron density, and the temperature:

$$\Delta\lambda_{1/2} = [1 + 1.75 \cdot 10^{-4} n_e^{1/4} \alpha (1 - 0.068 n_e^{1/6} T^{-1/2})]\, w n_e 10^{-16}$$

Here w is the shock electronic halfbreadth, calculated in [3] for an electron density of 10^{16} cm^{-3}; α is the parameter of the ionic broadening; n_e is the electron density; T is the temperature. This formula is valid for $\alpha < 0.5 \times 10^4 n_e^{-1/4}$, and satisfies the experimental conditions. Experiments show [6, 5] that the accuracy of calculations using this formula is 25-30%. Substituting the measured halfbreadths of the lines into the formula and using temperature dependence 4 (Fig. 5), proposed in [7], we obtain the results given in Fig. 4 and 5.

Figure 5 illustrates the change in the electron concentration over the thickness of the boundary layer for different moments of time. Curves 1, 2, and 3 relate to 5, 30, and 55 sec, respectively. There is a considerable rise in the electron density in the layers at the surface of the model. This can be explained by the presence of easily ionizable components in the decomposition products of the material. At the external boundary of the boundary layer, the electron density coincides with the electron density in an unperturbed flow.

The time dependence of the electron density 4 in Fig. 4 corresponds to the coordinate 1 mm (Fig. 5). The sharp rise in the electron density at the start of the process (up to 25 sec) coincides with the relaxation period for the parameters which characterize the process of decomposition of the material (the temperature of the surface, the linear entrainment, the depth of the coked layer). The time required for these parameters to reach quasi-steady-state conditions coincides with the time required for the electron density to reach quasi-steady-state conditions. The change in the electron density in this interval of time is insignificant.

3. Thus, it has been established experimentally that, in the boundary layer at the surface of a decomposing model made from an asbestos plastic, in a high-temperature flow of air (at a pressure of 1 atm) the electron density reaches 1.2×10^{16} cm^{-3}, which is four times greater than the electron density at the outer limit of the boundary layer.

The change in the electron density in the boundary layer as a function of time is in qualitative agreement with the change in the parameters which characterize the process of decomposition of the material.

It must be noted that the low value of the electron density in layers adjacent to the surface of the material may, in principle, exert a considerable effect on heat and mass transfer; this demands a special investigation.

The results obtained are in qualitative agreement with the calculations presented in [1], although the sharp drop in the electron density directly at the boundary of the model which is predicted in this article was not observed in the above experiments. This is explained by the fact that, in the experiments, the temperature of the surface of the model was considerably higher than the surface temperature assumed in the above article.

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