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STRUCTURE OF THE PLASMA FLOW FORMED IN MULTISTREAM MIXING CHAMBERS OF DIFFERENT TYPE

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The results of spectral measurements of the temperatures of an air plasma flow are presented and analyzed.

The most important characteristics of plasma reactors for processing gas-phase stock, solutions, and dispersed materials depend on the parameters of mixing and heat transfer between the plasma flow, the system being treated, and the walls of the reactor channel. In order to intensify the mixing and heat transfer between the systems being treated with the plasma flows and to reduce heat flow into the wall different structures for the plasma reactors are under study. The review and analysis of well-known plasma reactors performed in [1] and subsequent publications show that one of the most widely used and, probably, most promising setups is a plasma reactor based on the multistream mixing chamber.

Studies of mixing chambers — the main element of a plasma reactor — are being conducted along different lines. In one of the latest works [2] the gas-dynamics of a three-stream mixing chamber is studied and it is shown that even without the introduction of the components being treated the plasma flow is characterized by a complex structure, the presence of reverse flows, and in some cases recirculation zones. Heat transfer in a plasma reactor with a three-stream mixing chamber is analyzed in [3-6]. It is shown that the use of cylindrical and conical mixing chambers with radial and tangential injection of the plasma jets [3, 4, 6] makes it possible to regulate the heat flow into the wall of the reactor and thereby affect the efficiency of the entire setup. Control of the plasma flow structure is achieved both by changing the configuration of the chamber itself and by placing plasmatrons at a definite angle to the axis of the plasma unit.

In this connection, aside from determining the gas-dynamic and thermal characteristics of the objects under study, it is desirable to study the temperature distribution over their

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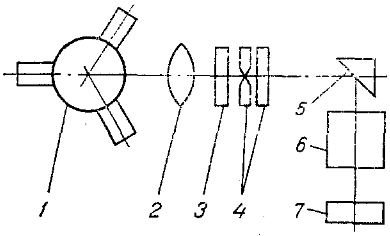

Fig. 1. Optical layout of the spectral measurements: 1) mixing chamber with three electric-arc plasmatrons; 2) focusing lens; 3) modified Hartman diaphragm, 4) input slit and collimator of spectrograph; 5) dispersing system of the spectrograph; 6) objective; 7) recording apparatus.

cross section. The results of such studies for cylindrical mixing chambers with radial injection of plasma jets are presented in [1].

In this work spectral methods are used to investigate the temperature distribution at the output from conical and tangential mixing chambers with the following geometric and state characteristics. For a conical mixing chamber the bases are 0.01 and 0.1 m in diameter, the chamber is 0.08 m high, the angle of inclination of the axes of the plasmatron nozzles to the axis of the chamber equals 60°, the nozzles are 0.017 m in diameter, the total flow rate of the plasma-forming gas equals 4.9-5.6 g/sec, 125-140 kW of electrical power is supplied to the plasmatron, the power of the plasma jets in the mixing plane equals 70-80 kW, the mean-mass enthalpy h_{g_1} and the temperature $\bar{T}_{g_1}$ of the plasma flow equal 12-16 kJ/g and 5000-6200°K, respectively, and the efficiency reaches 0.89. The tangential mixing chamber is a cylinder 0.05 m in diameter and 0.1 m high, on which plasmatrons with nozzles 0.017 m in diameter are placed tangentially. The total flow rate of the plasma-forming gas equals 7.8 g/sec, 165-180 kW of electrical power is supplied to the plasmatrons, the power at the inlet into the mixing chamber equals 100-115 kW, and the mean-mass enthalpy h_{g_1} and temperature $\bar{T}_{g_1}$ of the plasma flow equal 10.0-12.5 kJ/g and 5000-5700°K, respectively. Thus both setups studied have comparable parameters.

The distribution of the temperature of the plasma flow over the cross section of the conical and tangential mixing chambers at their outlet, like previously [7], was measured by the method of relative intensities of copper lines with wavelengths of 5105, 5153, and 5220 Å. The spectra were recorded with an ISP-51 spectrograph with a chamber F = 270 mm. A diagram of the mixing chamber is shown in Fig. 1. The plasma flow formed in the mixing chamber 0.005 m from the cutoff of the mixing chamber was projected by an achromatic condenser F = 210 mm through a modified Hartman diaphragm onto the input slit of a spectrograph. The limiting slit width ℓ = 20 μm.

The best-known method for determining the plasma temperature — the method of relative intensities — is based on the fact that the densities of different excited states are proportional to the products of the statistical weights and the Boltzmann factors of these states. According to this, the temperature T is inversely proportional to the logarithm of the ratio of the total intensities of lines arising with transitions from different upper levels [8], under the conditions that no line is subjected to self-absorption and local thermodynamic equilibrium (LTE) holds in the plasma flow.

In accordance with the procedure for performing measurements of spectral lines, photographs of both the image of the plasma jet, projected by a simple condenser onto the slit of the spectrograph, and of the image of the arc between iron electrodes (obtained with a DG-2 arc generator), taken through a nine-step attenuator placed in front of the spectrograph slit, were made on the same photographic plate.

Using an MF-2 microphotometer, photometric measurements were performed, taking into account the background blackening, on the copper lines obtained on the photographic plate. The photographs of the spectrum of the arc between the iron electrodes were used to construct a graph of the blackening of the photographic plate as a function of the intensity transmitted by the attenuator in the form log S = f log I, and the logarithm of the sum of the line intensities and the background intensity $\log(I + I_{f'})$ and the logarithm of the background $\log I_{f'}$ were obtained from it. Then the intensity of the background on the photographic plate $I_{f'}$ and the intensity of the spectral line I were calculated.

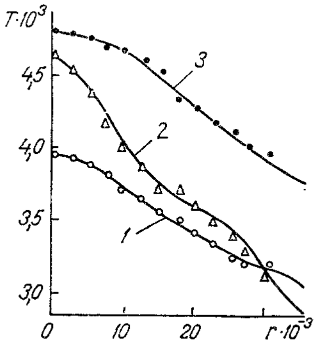

Fig. 2. Radial distribution of the electron temperature in the plasma flow at the cutoff ($\overline{L}$ = 0.8) of the conical mixing chamber: 1) G_g = 4.91 g/sec; N = 124.5 kW; $\overline{T}_{g_1}$ = 5800 K; 2) 5.62; 138.5; 5600; 3) 4.82; 140.8; 5800. T, K; r, m.

The temperature was determined using the formula

$$kT = \frac{E_1 - E}{\ln(I\lambda^3 g_1 f_1'/I_1\lambda_1^3 gf')}.$$

LTE was checked using the copper lines with wavelengths 5220, 5153, 5105, 4530, and 4022 Å and excitation potentials of 6.19, 6.19, 3.82, 6.55, and 6.87 eV, respectively. All lines used for the measurements had one distinct maximum, and the points corresponding to these copper lines, represented in the form of the dependence log ($I\lambda^3/gf'$) = f(E), were described by a straight line, indicating the presence of LTE and the absence of self-absorption and self-reversal [9] in the plasma flow formed in a three-jet mixing chamber.

The spectral lines subjected to photometric analysis on the microphotometer were identified with the help of an atlas of spectral lines. The graphs obtained for the intensity distribution along the radius of the plasma jet had a distinct symmetry, which, in transferring to the calculation of the temperatures, made it possible to take into account the geometry of the jet by Abel's method [9]. The error in the experiment, evaluated from two to three parallel measurements of the operation of the setup in one state followed by recording of the spectra on the same photogrpahic plate, fell into the range 5-12%, while with Abel's transformation taken into account it fell into the range 3-16%.

Figure 2 shows the radial dependence of the temperature of the plasma flow formed in a conical mixing chamber with different flow rates of the plasma-forming gas and different powers at the inlet. Increasing the injected power from 124.5 to 140.8 kW while maintaining the gas flow rate approximately constant (4.9 and 4.8 g/sec) increases the temperature on the axis of the flow from 3960 to 4800°K while maintaining the analogous temperature distribution over the cross section of the mixing chamber.

Changing the flow rate of the plasma-forming gas from 4.8 to 5.6 g/sec while maintaining the injected power approximately constant (148.8 and 138.6 kW) causes a deformation of the profile of the temperature distribution and an insignificant drop in temperature to 4650°K. In addition, the temperature on the axis of the mixing chamber drops approximately by 120°K, while the change in the temperature at $r = 0.5\ r_{max}$ already reaches 800°K and at $r = r_{max}$ it equals 1000°K, i.e., as the flow rate of the gas is increased the profile becomes less full and approaches the profile characteristic for a laminar flow.

The structure of the plasma flow formed in the cylindrical mixing chamber with tangential injection of plasma jets, as can be seen from Fig. 3, is much more complicated than for radial injection of jets in the cylindrical and conical mixing chambers. In all regimes studied there is a dip in the temperature along the axis of the mixing chamber. The ratio T_{min}/T_{max} reaches values of 0.54, 0.64, and 0.665, where T_{min} and T_{max} are, respectively, the minimum and maximum value of the temperature on the axis. This is probably explained by the fact that for tangential injection of plasma jets the cooler plasma-forming gas flows into the zone of the mixing chamber near the axis from regions of the discharge chamber of the plasmatron near the walls. One must assume that the possibility of deformation of the spectral temperature profiles (curves 1 and 3 in Fig. 3) is a result of the different strengths of the

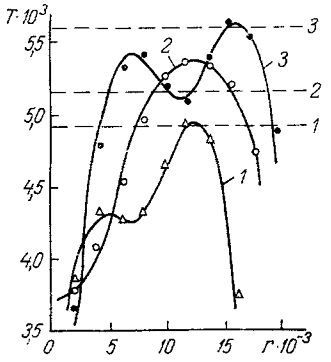

Fig. 3

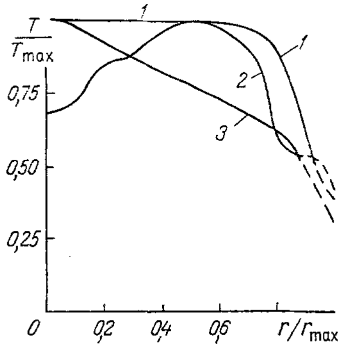

Fig. 4

Fig. 3. Radial electron temperature distribution of the plasma flow at the cutoff ($\bar{L}$ = 1.0) of the tangential mixing chamber for G_g = 7.8 g/sec: 1) N = 100.6 kW; 2) 107.1; 3) 115.7; the broken lines show $\bar{T}_{g_1}$.

Fig. 4. Profiles of the relative temperatures of plasma flows formed in multijet mixing chambers of different types: 1, 2) cylindrical with radial and tangential injection of jets, respectively; 3) conical with radial injection of jets.

injected plasma jets. Equal strengths lead to a more uniform distribution of the temperature (curve 2 in Fig. 3). The flow rate of the plasma-forming gas is the same for all three regimes shown in Fig. 3.

Increasing the strength of the plasma jets injected into the mixing chamber increases the maximum value of the spectral temperature T_{g_1} (4920, 5400, 5600°K for regimes 1, 2, 3, respectively). In all cases, as one can see from Fig. 3, the value of the maximum spectral temperature agrees well with the mean-mass temperature, determined by the method of calorimetry ($\bar{T}_{g_1}$).

Figure 4 shows the relative temperature T/T_{max} as a function of the relative radius r/r_{max} at the outlet from a cylindrical mixing chamber with radial and tangential injection of plasma jets and a conical mixing chamber with radial injection of jets. The comparative data shown in the figure confirm the previously drawn conclusions regarding the fact that the profile of the temperatures in the conical and tangential mixing chambers is nonuniform. In addition, the data of [3, 5] regarding the higher efficiency of the conical mixing chamber compared with that of the cylindrical mixing chamber are explained qualitatively: the higher efficiency is due to the deformation of the plasma flow (and the corresponding temperature profile) formed in the multijet conical mixing chamber. This makes it necessary to take into account the information obtained in choosing the type of plasma reactor for a concrete technological process. From the standpoint of treating dispersed material in a plasma reactor, the profile 1 (Fig. 4), formed in the cylindrical mixing chamber with radial injection of plasma jets, is preferable, but the efficiency of such a setup is lower owing to the increase in the thermal losses in the wall.

The efficiency of the conical mixing chamber is higher, and the maximum temperature on the axis of such a chamber is also higher, which is what determines the most desirable zone for injecting the material being processed. When the material is injected along the axis, taking into account the cone of expansion of the particles, the profile of the temperatures over the cross section of the mixing chamber will be smoothed, as a result of which the particles should be subjected to identical conditions. Injection and processing of dispersed solutions in a reactor with such a mixing chamber can be recommended for the same reason.

Axial injection of the material being processed into a tangential mixing chamber is contraindicated; it should be shifted into the zone of maximum temperatures. In this case preference should probably be given to tangential injection in the plane perpendicular to the axis of the reactor or at some angle to it.

In conclusion, it should be noted that since the method used for recording and processing the spectrograms is valid only for stationary processes, the results obtained from the measurements of intensities and temperatures should be regarded as information about the time-averaged and volume-averaged flow pattern.

NOTATION

h_{g1}, enthalpy of the flow in the plane of mixing of the plasma jets; T_{g1}, temperature; F, focal length; ℓ, expansion limit of the slit; I, intensity of the lines; λ, wavelength; g, statistical weight; f', oscillator strength; E, excitation energy; and k, Boltzmann's constant.

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THEORETICAL STUDY OF THE KINETICS OF AUSTENITIZATION IN STEELS WITH HEATING BY CONTINUOUS LASER RADIATION

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A determination is made of the degree of austenitization taking place with the diffusional displacement of grain boundaries in different regions affected by laser radiation (LRR). The process of the formation of stable austenite is analyzed.

Laser quenching is characterized by a short time of exposure and high cooling rates. Regions exposed to laser radiation have sections heated to different temperatures, from room temperature to the melting point. In connection with this, different stages of austenitization can be fixed in different sections of an LRR. Here, the stage depends on the temperature—time conditions.

The process of pearlite austenitization consists of the formation of austenite nuclei, a polymorphic $\alpha \to \gamma$-transformation, dissolution of cementite, and diffusional redistribution of carbon. At a high rate of laser heating the formation of austenite nuclei is activated as a result of a sharp reduction in the critical dimensions of the nuclei. The nucleation mechanism can also change, from a diffusional mechanism to a shear or athermal mechanism. Thus the nucleation process cannot affect the kinetics of austenitization.

When pure iron is heated above the temperature A_{C_3} (911°C), the formation of the austenite grain can be examined in two stages: restructuring of the crystalline lattice; concentration-induced redistribution of carbon with the dissolution of cementite [1]. At lower temperatures, these stages can be examined together as a transformation with a concentration-

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