THE INITIAL SECTION OF A PLANE NONISOTHERMAL JET DEVELOPING UNDER ASYMMETRIC CONDITIONS WITH AND WITHOUT COMBUSTION

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A solution of the problem obtained with the method of integral relations is given here. It is obtained in the form of simple algebraic formulas for the boundaries of the mixing zones on both sides of the jet, the position of the flame front, and the axis of the jet at the end of the initial section. It is found that asymmetry of the boundary conditions has a substantial effect on the characteristics of the jet: the position of the axis of the jet at the end of the initial section can change its sign, depending on the temperature ratio at the boundaries of the jet and for given ratios of the velocity at the boundaries of the jet to the velocity of the jet outflow, the length of the initial section can change several fold.

Development of a gasdynamic theory and perfection of the methods for calculation of the primary zone in the combustion chamber as well as working out of recommendations for updating prospective schemes of gas-turbine plants of different types require solution of some gasdynamic problems on the flow in the primary zone with and without combustion. One such problem is a plane nonisothermal jet developing in asymmetric conditions with and without combustion.

At present there are only works on the theory of combustion of an axisymmetric flame with the same conditions at its boundary, which does not correspond to the flow pattern in the primary zone of the combustion chamber, where the fuel gas is supplied from the nozzle as a radial jet that is transformed subsequently into a circular jet. Between this jet and the wall there is a circular air flow from the swirler, and in the center a weak circulating flow of combustion products appears due to ejection of a transverse jet in the downstream flow. Thus, the circular jet of fuel develops under asymmetric conditions and the flame front exists only on one side, on the side of the air flow. Generally speaking, if not all of the oxygen was used in combustion, it can get into the reverse flow and a second flame front can arise on the side of the flow of combustion products. In any case combustion occurs in substantially asymmetric conditions.

With the radius of the chamber $R_c$ exceeding substantially the thickness of the circular jet, we can assume that $R_c \to \infty$ and consider not a circular but a plane jet with different conditions on its upper (on the side of the oxidant) and the lower (on the side of circulating combustion products) boundaries.

Now we will consider a solution of the problem on the initial plane nonisothermal jet developing in asymmetric conditions with and without combustion with the method of integral relations.

1. Let the jet flow out of an infinitely long slot of width $b_0$ with velocity $u_0$ and temperature $T_0$ into a space in which from the one side a flow moves with velocity $u_{31}$ and temperature $T_{31}$ and from the other, a flow moves with the velocity $u_{32}$ and temperature $T_{32}$. Since the conditions at the boundaries of the jet are different, mixing zones are developed in different conditions and at the end of the initial section the boundaries of the core converge to a point not on the line $y = 0$ emerging from the center of the slot but on some other line that should be determined in the process of solution, i.e., in this case the axis of the jet does not coincide with the line $y_0(x)$. A schematic diagram of the initial section of the jet developing in asymmetric conditions is shown in Fig. 1a.

It is assumed that in the initial section the velocity and temperature profiles are similar and described by known expressions, in this case for description of the flow it is necessary to determine five quantities, namely, $y_1$, $y_2$, $y_3$, $y_4$, and $y_5$.
Fig. 1. Schematic diagram of a jet with asymmetric boundary conditions: a) nonisothermal jet; b) jet with a combustion flame.

$y_{21}$, $y_{12}$, $y_{22}$, and $y_0$. In accordance with the method of integral relations one can use two integral conditions of conservation of excess momentum of the jet in two parts of the jet developing in different conditions and two respective integral energy equations. For determination of $y_0$ one can use the condition that the boundaries of the potential core in the upper and lower zones converge at a point. Since the pressure across the jet may be assumed constant, the velocity in the potential core of the jet is also invariable, and it follows from the continuity equation that the transverse velocity is zero over the whole region of the potential core. Integral relations for determination of four boundaries of the mixing zones have the form [1]:

\[
\frac{d}{dx} \int_{y_i}^{y_{1i}} \rho u (u - u_{3i}) dy = 0 , \quad (1.1)
\]

\[
\frac{d}{dx} \int_{y_0}^{y_{1i}} \rho u (u - u_{3i})^2 dy = 2 \int_{y_0}^{y_{1i}} \rho u v \frac{\partial (u - u_{3i})}{\partial y} dy \quad (i = 1 \text{ for the upper part of the jet and } i = 2 \text{ for its lower part}).
\]

The boundary conditions were used in derivation of the integral relations:

\[
u = u_{3i} \quad \text{when} \quad y = y_{1i} ; \quad (1.2)
\]

\[
u = u_0 \quad \text{when} \quad y = y_{2i} .
\]

It will be assumed that in the cross-sections of the mixing zones the velocity profiles are similar and described by a third-power polynomial, whose coefficients are determined from boundary conditions (1.2), i.e.,

\[
\frac{u - u_{3i}}{u_0 - u_{3i}} = f (\eta_i) = 1 - 3\eta_i^2 + 2\eta_i^3 , \quad (1.3)
\]

where

\[
\eta_i = \frac{y - y_{2i}}{\delta_i} . \quad (1.4)
\]

After some transformations, substitution of Eqs. (1.3) and (1.4) in Eq. (1.1) gives two ordinary differential equations.