CIRCULATORY FLOW IN THE INTER-JET ZONE OF A SYSTEM OF FREE TURBULENT JETS

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Systems of jets are widely used in engineering (ventilation, furnace processes, heat treatment of various surfaces, gaseous fuel combustion, and so on). Therefore, a study of the nature of the flow and the laws governing heat and mass transfer in systems of turbulent jets is useful for practical application. The primary (jet) flow zone has been quite thoroughly studied (see, for example, [1-4]). The circulatory (reverse) flows that arise in the inter-jet zone near the nozzle block surface play a destructive role in high-temperature flows. The result is overheating and burn-through of the nozzle block surface. In diffusion flame systems with the presence of powerful circulatory flows there is no influx of air (oxidizer) from outside into the jet flow zone, and the combustion in the central part of the system degrades. Circulatory flow has not been adequately studied, for example [5, 6] only note the presence of circulatory flows in a system of plane parallel jets.

We shall present the results of an experimental study of the pressure and temperature distributions in the circulation zone of a system of axisymmetric parallel turbulent air jets. The experimental setup and the measurement technique were described in [3, 4]. An SFOTs 40/0.5-Tsl electrical heater with a centrifugal fan was used to improve and stabilize the heating of the jets. The centers of the jets were located at the corners of squares as shown in Fig. 1, where s is the spacing, m; $d_{0i} = d_0$ are the initial jet diameters, m.

We obtained two groups of data: 1) with a constant number of jets (n = 4) we varied the spacing $1.0 \leq s^0 = s/d_0 \leq 2.0$), Figs. 2-4; 2) with fixed spacing (s^0 = const) we varied the number of jets ($4 \leq n \leq 144$), Figs. 5, 6.

Figure 2 shows the data from measurement of the statistical average pressure in the circulation zone of a system of four jets with different spacing. Here p^0 is the dimensionless pressure, referred to the dynamic head; ρ is the air density, kg/m³; u_0 is the initial jet velocity (at x = 0), m/sec; R is the distance from the center of the system to the center of the jet ($R = \sqrt{0.5}s$), m; $r_0 = d_0/2$. The pressure probe was a slender tube (needle), the end of which was sealed, with a side opening for the pressure. Some underpressure is observed in the circulation zone. With increase of s^0 the pressure rapidly equalizes with the ambient pressure.

We note that at various points of the circulation zone space the average values of the pressure and temperature are nearly the same, therefore the data presented relate to the point x = 2 to 4 mm, z = y = 0 (Fig. 1).

In the limits of the ventilation regime it was not possible to obtain reliable results on the velocity in the circulation zone because of the highly chaotic nature of the flow. Therefore, it seems to us that measurement of the temperature in the inter-jet zone is a reliable and accessible technique for practical use.

Figure 3 shows the variation of the temperature in the circulation zone in a system of four jets with variation of the relative spacing and the initial velocity u_0 and temperature t_0, K (points 1-3 correspond to u_0 = 25.5, 22.1, 24.2 m/sec, Δt_0 = 16.9, 10.1, 13.4 K; Re = $1.69 \cdot 10^4$, $1.46 \cdot 10^4$, $1.60 \cdot 10^4$). The perforation diameter, i.e., the initial diameter of an individual jet, $d_0 = 10^{-2}$ m. Figure 4 shows the data for a nozzle with perforation diameter $d_0 = 2 \cdot 10^{-2}$m (points 1-4 correspond to u_0 = 21.0, 24.2, 22.5, 28.5 m/sec, Δt_0 = 8.2, 12.0, 10.7, 20.0 K, Re = $2.69 \cdot 10^4$, $3.21 \cdot 10^4$, $2.98 \cdot 10^4$, $3.78 \cdot 10^4$). We see from these figures that for fixed n the relative spacing s^0 is the determining factor. The value of Δt_1^0 does not change significantly as a function of the initial velocity and temperature of the jet, $\Delta t_1^0 = f(n, s^0)$. Here $\Delta t_1^0 = \Delta t_1/\Delta t_0$, $\Delta t_0 = t_0 - t_2$, $\Delta t_1 = t_1 - t_2$, t_1 is the temperature in the circulation zone, t_2 is the ambient temperature.

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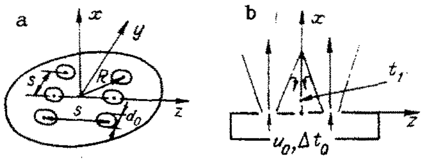

Fig. 1

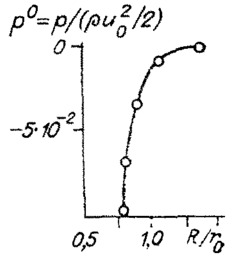

Fig. 2

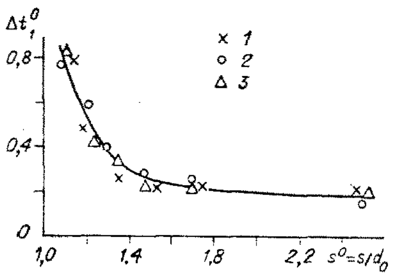

Fig. 3

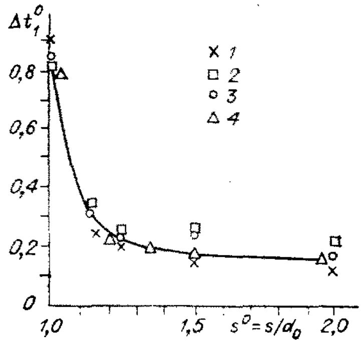

Fig. 4

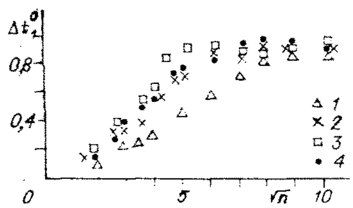

Fig. 5

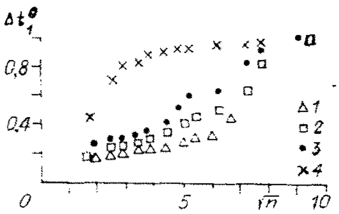

Fig. 6

For the system of four jets there is a critical value of the dimensionless spacing $s_* \cong 1.4$. For $s^0 < s_*$ the circulatory flow is intense, for $s^0 > s_*$ it can be neglected.

Figures 5 and 6 show the values of the dimensionless temperature differential when $s^0 = \text{const}$ and the number of jets is varied (Fig. 5: $28 \leq u_0 \leq 30$; $8.5 \leq \Delta t_0 \leq 11.2$; $10.46 \cdot 10^3 \leq \mathrm{Re} \leq 11.95 \cdot 10^3$; points 1-4 correspond to $s^0 = 2.0, 1.6, 1.3, 1.5$; Fig. 6: $32.3 \leq u_0 \leq 33.4$; $\mathrm{Re} \cong 13.14 \cdot 10^3$; $9.7 \leq \Delta t_0 \leq 11.3$; points 1-4 correspond to $s^0 = 2.5, 2.0, 1.7, 1.2$). We measured the temperature in various systems with fixed but different s^0. Thus, s^0 acts as the parameter in determining the relation $\Delta t_1^0 = f(\sqrt{n}, s^0)$. We see that the nature of the variation of $\Delta t_1^0 = f(\sqrt{n})$ depends on the relative spacing. For $s^0 > s_*$ the curve of $\Delta t_1^0 = f(\sqrt{n})$ is convex downward, while for $s^0 < s_*$, it is convex upward. In the systems of jets, when $s^0 \cong s_*$ a linear relationship is observed between Δt_1^0 and $\sqrt{n}$. Consequently, the value of the dimensionless spacing $s_* \cong 1.4$ plays a special role in this case as well, i.e., it is the critical number. For the systems of jets shown in Figs. 5 and 6, $d_0 = 6 \cdot 10^{-3}$ m. The Reynolds numbers were calculated on the basis of the initial diameter of the individual jets, i.e., using d_0. The viscosity of the air corresponded to its value at room temperature.

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