EFFECT OF SOUND RADIATION ON THE MIXING OF FLOWS WITH APPRECIABLY DIFFERENT TEMPERATURES

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The influence of acoustic oscillations on the mixing of helium and high-temperature nitrogen is investigated. The optimal radiator frequency and power ranges are determined.

It has been shown in studies [1, 2] of the influence of low-frequency oscillations on the parameters of free low-temperature jets that "instantaneous" mixing of a jet with the surrounding medium can be attained under certain conditions; i.e., exit flow with an initial section of zero length is obtained, thus demonstrating the possibility of deliberately affecting the mass-transfer process in a submerged free turbulent jet.

The effect of low-frequency oscillations on mixing jets has a resonant character and is caused by intensification of the mass-transfer process due to variation of the turbulence scale [3] and deeper penetration of particles from the outer, higher-energy part of the boundary layer into the inner part.

We have investigated the influence of low-frequency irradiation of flows in connection with the interaction of high-temperature jets (nitrogen plasma) colliding at the center of the mixing chamber used in [4, 5] with a cold helium drift flow.

The influence of sound irradiation on a gas flame under wall-confinement conditions has been investigated in [6], but the maximum flame temperature was considerably lower (by 1/2 to 1/3) than the temperature of nitrogen plasma.

Thus, a significant departure from the above-cited papers is the difference in the thermodynamic parameters of a flow confined by the walls of the mixing chamber.

The experimental arrangement is shown in Fig. 1.

Three nitrogen-plasma jets and the helium drift flow are injected into the mixing chamber 1. The audio oscillator 2 operates through the amplifier 3 to drive the magnetodynamic radiator 4, which irradiates the

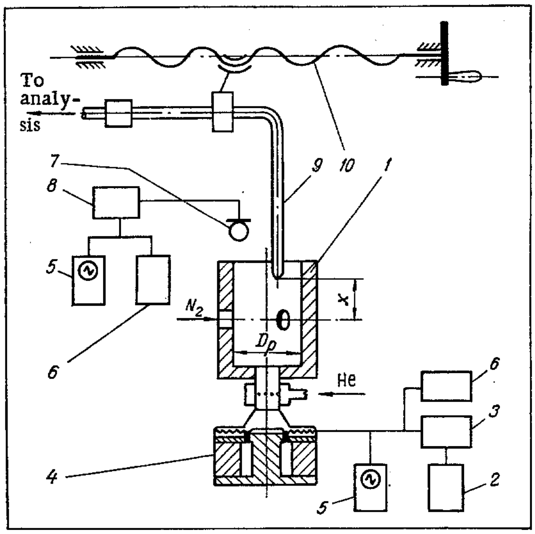

Fig. 1. Experimental arrangement.

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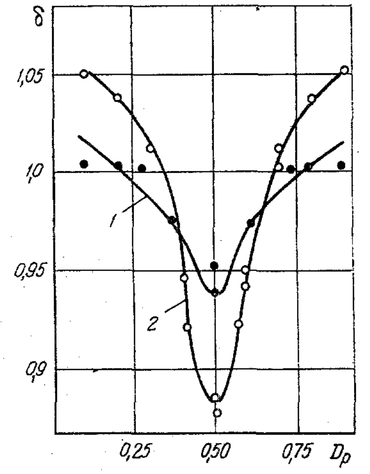

Fig. 2

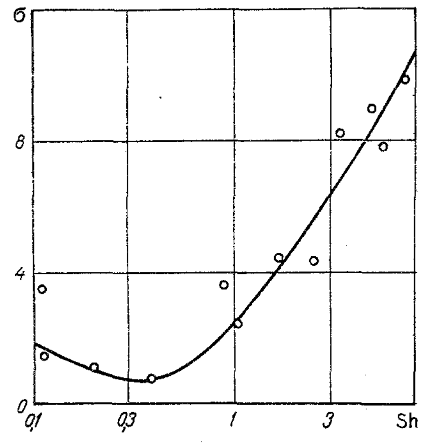

Fig. 3

Fig. 2. Variation of helium concentration over mixing chamber cross section: 1) with sound irradiation of flows (f = 2.4 kHz); 2) without irradiation.

Fig. 3. Helium concentration versus Strouhal number Sh. Vertical coordinate σ is the standard deviation of the helium concentration, vol. %.

drift flow. The waveform and frequency of the oscillations are monitored on the oscilloscope 5 and by the type F433/3 frequency meter 6. The microphone 7 in combination with the amplifier 8, frequency meter, and cathode-ray oscilloscope makes it possible to measure the natural frequency of plasmotrons in the mixing chamber in single- and multiple-jet operations as well as under the influence of the drift flow. Measurements are also performed for cold blowoff. It is seen in the figure that the generating and measuring apparatus is constructed on an audiometer circuit.

The probe 9, which is the same one as used in [7], is moved in the chamber cross section in the diametric plane and along the vertical by means of the coordinate positioning mechanism 10, which has a minimum displacement increment of 0.75 mm. The analysis is performed on a KhL-4M chromatograph.

As shown in [8], under definite conditions it is possible to create a gasdynamic situation in the mixing chamber such that mixing goes to completion over the length of one diameter; i.e., the length of the mixing zone is

$$k = \frac{x}{D_p} = 1, \tag{1}$$

where x is the distance from the plane of the plasmotrons to the end of the mixing zone and D_p is the diameter of the mixing chamber.

The required condition is

$$\psi = \frac{F\rho v^2}{F_c \rho_1 v_1^2} = 1, \tag{2}$$

where F is the area of the exit channel of the drift flow, F_c is the area of the plasma core formed upon collision of the plasma jets [8], ρv^2 is the characteristic hydrodynamic parameter of the plasma jet at the axis of the mixing chamber, and $\rho_1 v_1^2$ is the same parameter for the drift flow.

Our investigation was carried out in the frequency range from 15 Hz to 15 kHz. With the aid of a priori information from [9], together with measurements of the natural frequencies of the plasmotrons and the current and voltage fluctuations of a rectifier comprising VK-200 vacuum tubes in a Larionov circuit it was possible to delineate the following subintervals in which to expect the onset of resonance:

1) 10 to 50 Hz: pressure-fluctuation frequency of jet emerging from the plasmotron due to displacement of the arc-shunting spot in the plasmotron;

2) 150 to 450 Hz: fundamental frequency and first harmonics of Larionov rectifier supplying the plasmotrons;

TABLE 1. Results of Low-Frequency Irradiation of the Mixing Process for $k = 0.25$

f, Hz	Sh	ψ	σ, vol. %
0	—	0,63	9,2
50	0,01	0,63	8
450	0,1	0,63	5,1

3) 1900 to 2400 Hz: fundamental frequency of colliding high-temperature jets and drift flow.

Figure 2 gives the variation of the concentrations over the cross section of the mixing chamber at the level of two diameters, for the following parameters: diameter of mixing chamber 30 mm; power delivered to three plasmotrons 30 kW; mass flow rate of plasma-generating gas 1 m^3/h through each plasmotron; helium flow rate 1 m^3/h.

The relative helium concentration $\delta = \sigma/c_i$ is plotted along the vertical, where c_i is the initial concentration calculated from the total mass flow rates of the plasma-generating nitrogen and helium drift flow and σ is the standard deviation, calculated from standard relations, for the concentration over the cross section of the mixing chamber.

It is evident from the figure that without sound irradiation (curve 2) of the drift flow, δ, varies from 0.85 to 1.05, whereas with such irradiation at a frequency of 2400 Hz (curve 1) δ varies by less than a 2.5-fold range, i.e., the mixing figure of merit, which is an exceedingly important energy and technological parameter of plasmochemical processes, is substantially improved.

The results of the investigation at other frequencies at the half-diameter level are given in Fig. 3.

The standard deviation of the helium concentration, vol. %, is plotted along the vertical, and the Strouhal number is plotted on the horizontal axis:

$$\mathrm{Sh} = \frac{fd}{v_1}, \tag{3}$$

where f is the pulsation frequency of the drift flow, v_1 is the velocity of the drift flow at the nozzle orifice, and d is the nozzle diameter.

It is seen in the figure that the standard deviation of the helium concentration over the cross section of the mixing chamber at the half-diameter level relative to the entry axis of the plasma jets has a distinct minimum corresponding to Strouhal numbers less than unity.

For small values of Sh (less than 0.2 or 0.3) the effect of irradiation with low-frequency oscillations decreases, but in the interval $0.01 < \mathrm{Sh} < 1$ the opposite effect, i.e., flow deterioration, is obtainable only by increasing the acoustic power of the radiator to 10 W.

For high-frequency irradiation ($\mathrm{Sh} > 1$), on the other hand, an adverse effect of irradiation can be obtained at much lower powers, of order 4 to 6 W, and for $\mathrm{Sh} > 3$ it is impossible to improve the mixing process by sound irradiation. The optimal interval must be $0.01 < \mathrm{Sh} < 0.8$, which is considerably broader than the known range for free jets [8]. For small Sh, in general, satisfactory mixing can be obtained even at the quarter-diameter level, where the standard deviation of the helium concentration is lower by almost 1/2 than under similar conditions without sound irradiation. The data of these experiments are summarized in Table 1.

In all the experiments represented in the table, the ratio of the flow rates is 1 : 3 (He : N_2) for a total power input of 30 kW.

The influence of the intensity of sound irradiation of the helium drift flow is illustrated in Fig. 4.

The probe is situated at a height of 0.5 diameter from the plane of the plasmotrons on the axis of the mixing chamber. It is apparent from the figure that for low-frequency irradiation at a high acoustic radiator power the concentration is much greater than the initial value (25 vol. %); i.e., $\delta > 1.0$. For high-frequency irradiation with boosted power the helium concentration decreases ($\delta < 1.0$), and the same net effect can be obtained by diminishing the acoustic power below a certain optimal limit.

Standard processing of the experimental results makes it possible to determine the dependence of the acoustic power of irradiation of the drift flow for optimal mixing:

$$W = \varphi \rho v^2 \text{ w}, \tag{4}$$

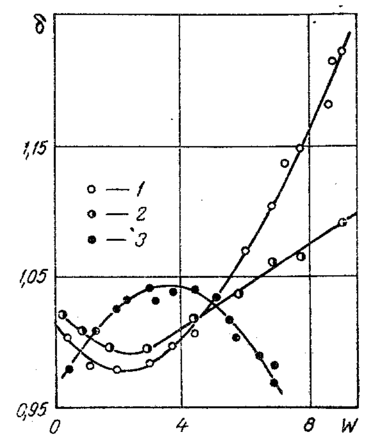

Fig. 4. Relative concentration δ versus acoustic power W, watts. Frequency interval: 1) 50 to 150 Hz; 2) 500 Hz; 3) 1900 to 5000 Hz.

where v is the velocity of the plasma at the orifice of the plasmotron nozzle, m/sec, ρ is the density of the plasma, kg/m^3, and φ is an experimental coefficient having a value of 0.005 to 0.01.

The radiation intensity of the three plasmotrons as a function of the power input and mass flow of plasma-generating gas varied between the following limits in the experiments:

$$I = (1.5 - 35) \cdot 10^2 \quad \text{W/m}^2.$$

Measurements of the radiation of three colliding plasma jets have shown that the sound intensity level is about 160 dB, and a positive net effect is obtained for an intensity of irradiation of the drift flow at the level of 157 to 165 dB. A subsequent increase in the sound irradiation level does not yield any improvement in the mixing effect, a result that is attributable, as in the experiments of [10], to the onset of saturation.

Expression (4) permits an a priori estimate to be obtained for the required power of the acoustic radiator and a more precise determination of the required power is made experimentally from measurements of the sound-radiation intensity of the colliding plasma jets and the drift flow.

It is important to note that when ψ (2) differs appreciably from unity (in our experiments ψ varied from 0.63 to 630,000), the influence of sound irradiation is more pronounced, but the best mixing is obtained for ψ close to unity.

The experiments described above thus demonstrate the actual possibility of actively controlling an important technological parameter, namely, the mixing ratio of components in a high-temperature mixing chamber for the purpose of improving the technological and energy parameters of processes, and the results obtained here can be used in practice, for example, in combustion chambers, plasmochemical reactors, etc.

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