into nozzle; ΔP_{init}, additional pressure losses in initial section of channel caused by unsteady mode of flow; ΔP_{end}, end effect in flow of liquids in cylindrical nozzles; L_{init}, length of section of stabilization of velocity profile in channel; $l_{in} = nR$, inlet correction; l_{geom}, "geometrical" or "Couette" correction; η, viscosity of liquid; ρ, density; Re, Reynolds number; C_0, "hole constant."

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ENERGY-SEPARATION EFFECT IN A GAS EJECTOR

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A new effect of inverse energy separation in a gas ejector is discovered.

In those cases when the output cross section of a constricting mixing chamber of a gas ejector is blocked to discharge or when an ejector with a cylindrical mixing chamber works against a grid with a high enough hydraulic resistance the reverse discharge of the ejecting gas from the mixing chamber through the inlet for the ejected gas can take place. Despite the fact that such modes have an important effect on the operation of a whole series of systems, including the gas ejectors of supersonic wind tunnels and the test stands of jet engines, for example, especially during start-up, insufficient attention has been paid to their investigation.

In the course of experimental studies of the indicated modes of operation of a gas ejector operating on air at a high absolute pressure we discovered a new effect of inverse energy separation in a homogeneous gas stream which is initially steady with respect to the stagnation pressures and temperatures, consisting in the fact that the different air zones moving along the ejector acquire different temperatures, with some of them

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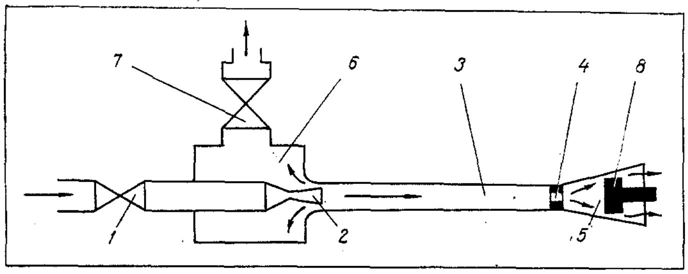


Fig. 1. Diagram of experimental apparatus: 1) inlet slide valve; 2) supersonic nozzle; 3) mixing chamber; 4) interchangeable diaphragm; 5) diffusor; 6) forechamber; 7) throttle; 8) near throttle.

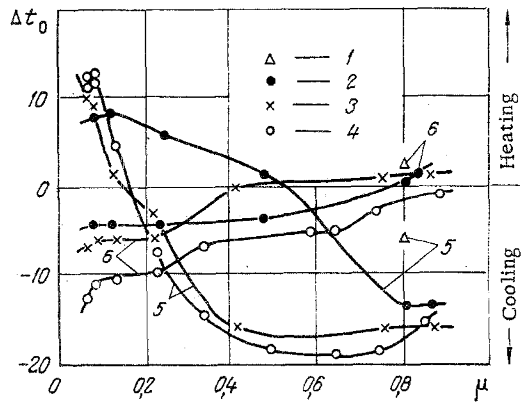
having temperatures far higher than the stagnation temperature of the entering air while others have a considerably lower temperature.

The experimental ejector had a supersonic conical nozzle with a throat diameter and exit cross section of 5.2 and 11.6 mm with an angle of expansion of 10° and a cylindrical mixing chamber with a diameter of 30.5 mm and a length of 10 diameters. The same nozzle cut off at 20 mm was used in subsequent studies. The exit cross section of the mixing chamber was shut off with interchangeable diaphragms. In one of them there was a central opening with a diameter of 4.8 mm while the other had no opening at all. Following the diaphragm there was a diffusor with a length of 154 mm and an expansion angle of 10°.

A diagram of the experimental apparatus containing the ejector is presented in Fig. 1. Compressed air from a compressor was fed through the inlet slide valve 1 into the supersonic nozzle 2 of the ejector and then into the mixing chamber 3. Part of the air was ejected through the opening in the diaphragm 4 into the atmosphere through the diffusor 5. The rest of the air flowed out of the mixing chamber into the forechamber 6 of the apparatus and was also vented into the atmosphere through the throttle 7. A near throttle 8 was placed in the diffusor to create a resistance after the diaphragm. The characteristic curves of the gas ejector were taken with the help of throttle 7 through the creation of a resistance in the forechamber 6. The air pressures at the inlet to the supersonic nozzle, in the forechamber, and before and after the diaphragm were measured with standard spring manometers. The air temperatures at the nozzle inlet, in the forechamber, in the mixing chamber (at a distance of 95 mm from the inlet), and before the diaphragm were recorded with KhK thermocouples connected to an ÉPP-09M3 automatic electronic potentiometer with "interrogation" of the thermocouples every 5 sec and continuous recording on a graph. The air flow rate at the inlet to the ejector was measured with a standard diaphragm while the air flow rate through the opening in diaphragm 4 was determined from the pressure drop. All the studies were conducted with an air pressure of 10-40 bar at the inlet to the ejector (at pressures less than 10 bar the energy-separation effect was practically not observed).

The experimental characteristic curves of the gas ejector are presented in Figs. 2 and 3. Characteristic curves taken with the diaphragm having an opening, through the creation of a resistance in the forechamber with throttle 7, when the near throttle 8 was fully open, are given in Fig. 2. The quantity Δt_0 at the end of the mixing chamber was found as the difference $(t_{03} - t_{01})$ while in the forechamber it was found as the difference $(t_{02} - t_{01})$. The original supersonic nozzle was used in these tests. As the throttle was closed the pressure in the forechamber increased and the flow rate of air through the diaphragm, the pressure drop at which was supercritical, increased accordingly. The maximum heating of the air at the end of the mixing chamber was 13°C for $p_{01} = 40$ bar, 10.5°C for $p_{01} = 30$ bar, and 8.5°C for $p_{01} = 20$ bar. With an increase in the pressure in the forechamber the heating at the end of the mixing chamber decreased, and starting with a certain time an inversion set in, i.e., the air at the end of the mixing chamber was no longer heated, but on the contrary was cooled, with the cold and heated zones gradually changing into one another along the length of the ejector. In these tests we obtained the following values of the maximum cooling of the air at the end of the mixing chamber; 19°C for $p_{01} = 40$ bar, 16°C for $p_{01} = 30$ bar, and 13.5°C for $p_{01} = 20$ bar. We note that in the pressure range of $p_{01} = 30$-40 bar and $t_{01} = 9$°C the absolute cooling of the air to minus 7.5-10°C was attained with throttle 7 fully closed in the mode when all the air flowed out through the diaphragm ($\mu = 1$). The corresponding integral throttle effects on a washer with an opening 4.8 mm in diameter measured under the same conditions were 8, 5, and 2.5°C.

In the forechamber, where inversion was also observed, i.e., with a certain resistance the air in it was heated rather than cooled, the maximum air cooling exceeded the indicated values of the throttle effect



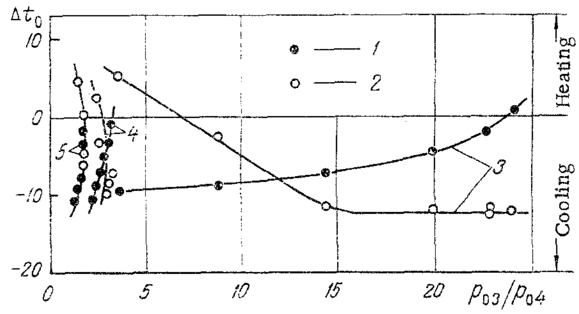


Fig. 2 Fig. 3

Fig. 2. Dependence of change in stagnation temperature of air on relative flow rate through diaphragm: 1) air pressure $p_{01} = 10$ bar; 2) 20; 3) 30); 4) 40 bar; 5) change in air temperature at end of mixing chamber; 6) the same in forechamber. Δt_0, °C.

Fig. 3. Dependence of change in stagnation temperature of air on pressure drop in forechamber with a fixed position of the near throttle: 1) parameters in forechamber; 2) the same at end of mixing chamber; 3) $p^0_{04} = 1$ bar; 4) 13; 5) $p^0_{04} = 25$; $p_{01} = 40$ bar; $t_{01} = -3\text{-}13$°C.

by only 1.5-5°C. The heating also proved to be less, while the start of inversion in the forechamber corresponded to a larger resistance (larger μ) than occurred for the processes at the end of the mixing chamber.

The further tests, in which the resistances in the forechamber and after the diaphragm with the opening were varied, were performed on the shortened nozzle. First with throttle 7 fully closed ($\mu = 1$) the energy-separation effect was tested through the creation of a resistance only by the near throttle 8. It was established that in a wide range of variation of the pressure ratio $p_{03}/p_{04} > 5$ at the diaphragm the cooling of air at the end of the mixing chamber remains practically constant and reaches 15°C for $p_{01} = 40$ bar and 12°C for $p_{01} = 30$ bar. The shortened nozzle in conjunction with the original mixing chamber showed poorer results. The heating of air in the forechamber was 1-4.5°C. It is interesting to note that a noticeable reduction in the cooling effect at the end of the mixing chamber begins even with supercritical pressure drops at the diaphragm ($p_{03}/p_{04} = 2\text{-}5$) and at the lower limit it reaches the magnitude of the integral throttle effect.

By fixing the position of the near throttle 8 (or by assigning the resistance p^0_{04} with throttle 7 fully shut, which is the same thing) it was possible to maintain the necessary pressure ratio p_{03}/p_{04} at the diaphragm while taking the characteristic curves with throttle 7. Such characteristic curves for three values of $p^0_{04} = 1$, 13, and 25 bar and $p_{01} = 40$ bar are presented in Fig. 3. As is seen, in the case of a fully open near throttle ($p^0_{04} = 1$ bar) the range of p_{03}/p_{04} for the inverse characteristic curves is rather large (curve 3) and as throttle 7 is opened the ratio p_{03}/p_{04} decreases from 24.2 to 3.7; μ varies linearly from 0.845 to 0.072; Δt_0 in the forechamber varies inversely from $\Delta t_{0c} = 3$°C to $\Delta t_{0h} = 9.7$°C, while at the end of the mixing chamber Δt_0 is transformed in the opposite way from $\Delta t_{0c} = 12.8$°C to $\Delta t_{0h} = 5.2$°C. A reduction in the range of p_{03}/p_{04} along the inverse characteristic curves is achieved by closing down the near throttle. For example, if $p_{04} = 13$ bar (curves 4) and throttle 7 is opened then the ratio p_{03}/p_{04} only decreases from 3.22 to 2.4 with a linear variation in μ from 1 to 0.076. In the forechamber Δt_0 takes on values of from $\Delta t_{0c} = 0.7$°C to $\Delta t_{0c} = 10.5$°C while at the end of the mixing chamber it takes on values of from $\Delta t_{0c} = 9$°C to $\Delta t_{0h} = 2.5$°C. For $p^0_{04} = 25$ bar (curves 5) with throttle 7 closed p_{03}/p_{04} only increases from 1.55 to 1.69; μ increases from 0.073 to 0.923; Δt_0 in the forechamber takes on values of from $\Delta t_{0c} = 10.5$°C to $\Delta t_{0c} = 2.3$°C, while at the end of the mixing chamber we have $\Delta t_{0h} = 4.5$°C and $\Delta t_{0c} = 6.8$°C, respectively. We note that in the indicated range of regulation of the near throttle the maximum cooling in the forechamber remains almost unchanged while the cooling effect is decreased at the end of the mixing chamber.

The investigation of the energy-separation effect in the gas ejector with the diaphragm without an opening ($\mu = 0$) and with the original nozzle was accomplished by creating a resistance in the forechamber. At the end of the mixing chamber the air was heated while in the forechamber it was cooled, with an inversion not being observed. The following maximum coolings and heatings of air were achieved: $\Delta t_{0c} = 2.5$°C and $\Delta t_{0h} = 31.5$°C for $p_{01} = 20$ bar; $\Delta t_{0c} = 6.5$°C and $\Delta t_{0h} = 48$°C for $p_{01} = 30$ bar; $\Delta t_{0c} = 12.5$°C and $\Delta t_{0h} = 59.5$°C for $p_{01} = 40$ bar. Under the same conditions with the shortened nozzle we have: $\Delta t_{0c} = 4.5$°C and $\Delta t_{0h} = 33$°C for $p_{01} = 20$ bar; $\Delta t_{0c} = 7.5$°C and $\Delta t_{0h} = 37.5$°C for $p_{01} = 30$ bar; $\Delta t_{0c} = 11.3$°C and $\Delta t_{0h} = 36$°C for $p_{01} = 40$ bar. Here the cooling effect proved to be somewhat higher at smaller pressure drops.

It is interesting to note that in the tests with the shortened nozzle the inversion could be detected at thermocouples mounted at a distance of 95 mm from the inlet to the mixing chamber, consisting in the fact that at a certain ratio of pressures p_{01} and p_{02} the heating zone extended for a considerable length of the mixing chamber from the blank diaphragm. The sound of the jet discharging from the forechamber changed simultaneously with the change in the readings of these thermocouples. In the transitional mode of a rise in the pressure p_{01} with the opening of throttle 7 the inversion set in at p_{01} = 28.5 bar. In the steady mode for p_{01} = 40 bar the inversion was achieved as follows. With p_{02} = 1 bar and t_{01} = +1°C we had Δt_{0c} = 11.3°C in the forechamber, Δt_{0h} = 36°C at the end of the mixing chamber, and Δt_{0h} = 24°C at the inlet to the mixing chamber. An increase in the resistance to p_{02} = 7 bar led to a change in the temperatures. They became Δt_{0c} = 9°C in the forechamber, Δt_{0h} = 40.5°C at the end of the mixing chamber, and Δt_{0c} = 2.3°C at the inlet to the mixing chamber.

NOTATION

p, pressure; t, temperature; Δt, temperature change; m, mass flow rate; $\mu = m_3/m$, relative mass flow rate. Indices: 0 pertains to stagnation parameters; 1: at the inlet to the ejector; 2: in the forechamber; 3: at the end of the mixing chamber; 4: parameters behind the diaphragm; c: cooling; h: heating.

PECULIARITY OF THE EFFECT OF PREHEATING THE MIXTURE ON THE PRESSURE DURING COMBUSTION IN A SEMIOPEN TUBE

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UDC 536.463

Data are presented on the effect of the mixture temperature on the propagation of a flame in a semiopen tube. It is found that preheating of the mixture can increase or decrease the combustion intensity depending on the coordinate of the ignition source.

The method of preliminary heating of the mixture has been tried in experimental searches for possibilities of increasing the efficiency of operation of pulse chambers [1, 2], which represent one variant of semiopen tubes.

A nichrome wire which was located along the axis of a tube 0.02 m in diameter and 0.31 m long served as the heater. A propane—air mixture, which was ignited with a spark ignition source, was burned in the tube.

It follows from the experimental data that preliminary heating of the mixture can have a twofold mutually opposed effect on the maximum pressure in the tube during the flash of the mixture. Thus, when the mixture is ignited near the open end of the tube a considerable increase in pressure is observed with an increase in heater power (curve 1 in Fig. 1), while when the mixture is ignited near the closed end of the tube a decrease in pressure was even observed (curve 2 in Fig. 1), which indicates a decrease in combustion intensity in this case.

Before the experiment it was assumed that in both cases the pressure should increase with heating because of the gradient increase in the normal propagation velocity of the flame. Near the heater the velocity will be higher than at points far from it. This leads to the elongation of the flame front, an increase in its area, and at the same time to a decrease in the combustion time of the mixture. And the faster the mixture burns, the less will be the energy dissipation and consequently the higher will be the pressure.

The arguments presented above are confirmed by the experimental data, but only for the case of propagation of the flame from the open end of the tube. In fact, as follows from interference motion pictures of the propagating flame, with heating the flame front is stretched out (Fig. 2b) in comparison with the case of a cold mixture (Fig. 2a) and the average propagation velocity of the flame increases by several times.

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