THE MIXING-CHAMBER LENGTH OF A SUPERSONIC EJECTOR FOR A ZERO EJECTION COEFFICIENT

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Results are presented from the experimental study of the effect exerted by the length of a cylindrical mixing chamber in a supersonic ejector on the efficiency of its operation. The physical mechanism of maintaining rarefaction is analyzed for a mixing-chamber length less than the optimum. It is established that the length of the mixing chamber of the ejector, ensuring maximum rarefaction for a zero coefficient of ejection, depends exclusively on M_a at the nozzle outlet. The optimum length of the mixing chamber is given as an empirical function of M_a.

In the theory of gas ejectors the problem of the efficient selection of mixing-chamber length is one of the fundamental problems determining the efficiency of ejector operation. Some of the work currently available, devoted to the calculation of an optimum mixing-chamber length (for example, [1, 2]), yields results clearly exaggerated relative to experiment. Thus, in the familiar reference [2] the relative length of the mixing chamber should be $\bar{l} > 12$, while in actual practice, from experimental data, it is generally assumed to be $\bar{l} = 6–8$.

Virtually all of the literature devoted to the selection of the mixing-chamber length deals with the case in which the ejection coefficient is not equal to zero. At the same time, there exists a large number of industrial devices designed to maintain constant—and as a rule, the maximum possible—rarefaction within a certain volume. Here the ejection coefficient is equal to zero.

For specific operational conditions it is frequently necessary to have a mixing chamber of minimum length. However, it is obvious that the optimum length of a mixing chamber should be a function of the flow characteristics and of the length of the free stream ahead of the inlet to the mixing chamber. Here the term optimum is understood to refer to such a mixing-chamber length as would ensure maximum rarefaction within the chamber for a minimum pressure ahead of the primary nozzle.

In view of the fact that there is presently no possibility of theoretically investigating the problem associated with the process of converting jet flow to channel flow, we carried out experimental research into the effect exerted by the length of a mixing chamber on the efficiency of the ejection process in the case of an ejection coefficient equal to zero.

A detailed description of the experimental installation is given in [4]. Figure 1 shows a diagram of the model.

The model represents a chamber of length $\bar{L}$ at whose outlet are positioned removable cylindrical mixing chambers of various lengths $\bar{l}$ and various lateral cross-sectional areas $\bar{f}_u$. The nozzle producing the jet of specified velocity is mounted at the opposite wall of the chamber. The length of the chamber was varied within limits $\bar{L} = 0–7$, the length of the mixing chamber was varied within the limits $\bar{l} = 0–6$, and its lateral cross-sectional area was varied within the limits $f_u = 0.7–25$. The M_a numbers (at the nozzle outlet) were equal to: 1.0; 2.02; 2.45; 2.85 3.37.

The experiments yielded the pressure P_c in the chamber as a function of the pressure P_0 ahead of the nozzle for various values of M_a, $\bar{f}_u$, $\bar{L}$, and $\bar{l}$. A typical function $P_c = f(P_0, \bar{l})$ is shown in Fig. 1, where we see that for any mixing-chamber length (with the exception of some limit) the nature of the functions $P_c = f(P_0)$ remains constant, i.e., as if there were no mixing chamber. The mechanism for maintaining

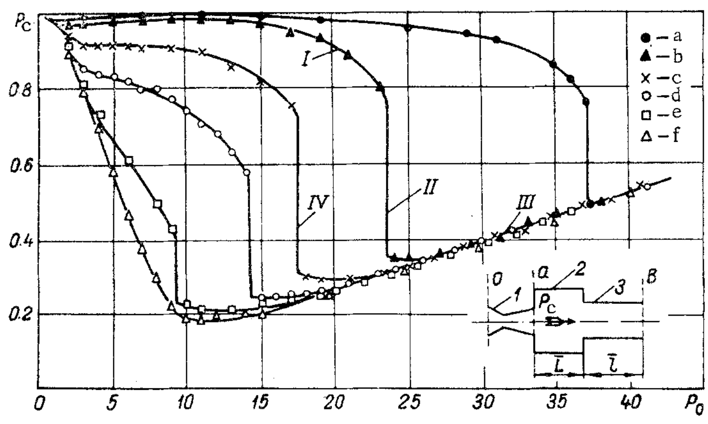

Fig. 1. Dependence of pressure P_c in chamber on pressure P_0 before nozzle at $M_a = 2.45$; $\bar{L} = 1.5$, and $\bar{f}_u = 4$: a) $l = 0$; b) 0.4; c) 1; d) 2; e) 4; f) 6; 1) nozzle; 2) chamber; 3) mixing chamber.

the rarefaction in the chamber when $\bar{l} = 0$ was studied in detail in [3], where it was established that the rarefaction in the chamber on segment I of the curve $P_c = f(P_0)$ is defined by the drop in pressure in the counterflow passing between the edge of the orifice and the

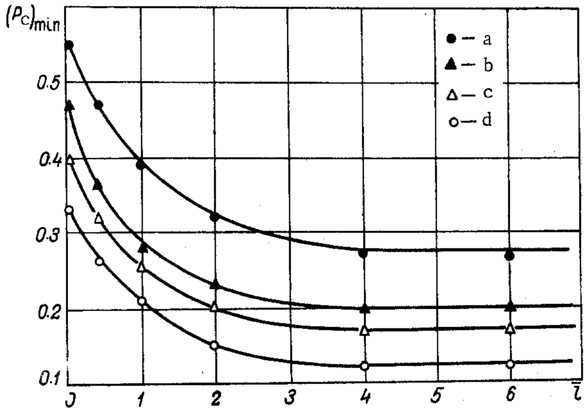

Fig. 2. Dependence of maximum rarefaction in chamber on mixing chamber length at $\bar{L} = 1.5$ and $M_a = 2.45$: a) $f_u = 2.25$; b) 4; c) 5.06; d) 9.

boundary of the main jet, compensating for the apparent mass of the main jet at length $\bar{L}$. The beginning of segment II corresponds to the nonsteady-flow regime in the counterflow, associated with the establishment within that flow of the critical velocity. Finally, segment III corresponds to the so-called regime of limit incalculability n_{lim} which is characterized by the linear relationship between the pressure P_c in the chamber and the pressure P_0 ahead of the nozzle. The beginning of the n_{lim} regime is defined by the instant of contact between the edge of the outlet orifice and the critical streamline in the boundary layer of the main jet.

In connection with the fact that the curves $P_c = f(P_0)$ when $\bar{l} > 0$ are similar to the analogous relationship when $\bar{l} = 0$, we should expect that the mechanism of maintaining P_c is identical in both cases. The pressure P_c for the same P_0 in segments I diminishes as $\bar{l}$ increases.

This may obviously occur only as a result of an increase in the velocity of the counterflow. As a matter of fact, if there is a drainage channel of length $\bar{l}$ at the outlet from the chamber, the apparent mass of the main jet and, consequently, the mass of air in the counterflow will no longer be defined by the length $\bar{L}$ of the jet, but by the quantity $(\bar{L} + \bar{l})$, i. e., they will increase as the length of the drainage channel increases. Moreover, it is completely obvious that as the length of the channel increases, the annular clearance between the edge of the outlet orifice and the external boundary of the main jet through which the air passes in the counterflow will diminish as a result of the expansion of the jet. These factors cause the velocity in the counterflow when $P_0 = \text{const}$ to increase as l increases, and the pressure in the chamber drops.

Naturally, the critical regime in the counterflow in this case sets in at a lower pressure P_0 ahead of the nozzle and with greater rarefaction of P_c in the chamber. When $\bar{l} = 6$ (in the case under consideration), the sharp drop in P_c begins even with low values of P_0. This indicates that the boundary of the jet immediately encompasses the edge of the outlet orifice.

Segment IV corresponds to the gradual conversion of the flow in the mixing chamber under the action of an increase in the flow rate through the main nozzle. The beginning of segment IV corresponds to the contact between the edge of the mixing-chamber orifice with the outer edge of the jet at section B; the end of segment IV corresponds to the onset of the n_{lim} regime, i. e., the contact of the edge of the inlet orifice of the mixing chamber with the critical streamline in the boundary layer. This conclusion follows from the fact that the magnitude of n_{lim} is not a function of the mixing-chamber length, as is seen from Fig. 1, since the segments of the curves corresponding to the n_{lim} regime coincide for various $\bar{l}$.

The magnitude of the maximum rarefaction in the chamber, all other conditions being equal, is a function of the mixing-chamber length, increasing with an increase in the latter, as is clearly seen from Fig. 2. However, beginning with some value of $\bar{l}$, the quantity $(P_c)_{min}$ ceases to be a function of $\bar{l}$. This phenomenon occurs for all values of $\bar{f}_u$, M_a, and $\bar{L}$.

Hence it follows that there is always some mixing-chamber length which ensures an optimum ejection regime. As we can see from Fig. 2, when $M_a = 2.45$ and $\bar{L} = 1.5$ there is no sense in increasing the mixing-chamber length above $\bar{l} > 4$. Here we will regard $\bar{l} = 4$ as optimum.

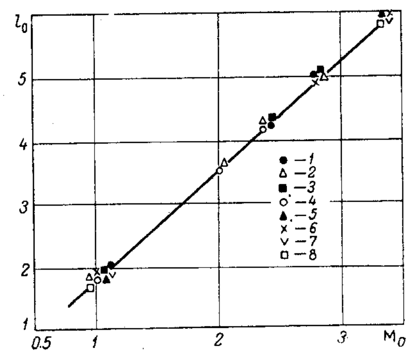

Fig. 3. Dependence of optimum length of mixing chamber on M_a: 1) $\bar{L} = 1.5$; $\bar{f}_u = 2.25$; 2) 1.5 and 4; 3) 1.5 and 5.06; 4) 1.5 and 9; 5) 7 and 2.25; 6) 7 and 4; 7) 7 and 5.06; 8) 7 and 9.

On the basis of a large number of experimental data we have derived $\bar{l}_0$ as a function of the Mach number M_a at the nozzle outlet, of the chamber length $\bar{L}$, and of the dimension of the outlet orifice $\bar{f}_u$. As we can see from Fig. 3, the quantity $\bar{l}_0$ is a function only of M_a and is independent of $\bar{L}$ and $\bar{f}_u$. The function $\bar{l}_0 = f(M_a)$ is linear in nature and may be approximated by the simple expression

$$l_0 = 1.8\ M_a.$$

Thus, on the basis of the investigations carried out, we can select the optimum mixing-chamber length for the condition $\bar{l} > \bar{l}_0$, where l_0 is defined from the cited formula.

NOTATION

M_a is the Mach number at nozzle outlet; l is the mixing chamber length; $\bar{l}$ is the relative mixing chamber length; d_u is the diameter of useful cross-section of mixing chamber; $\bar{f}_u$ is the relative area of useful cross-section of mixing chamber; P_c is the pressure in chamber; P_0 is the stagnation pressure before nozzle; L is the chamber length; $\bar{L}$ is the relative chamber length; d_a is the diameter of outlet cross-section of a nozzle; f_a is the area of outlet section of a nozzle; n_{lim} is the limiting degree at which it is impossible to predict outflow of a jet; $\bar{l}_0$ is the relative optimum length of mixing chamber.

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THE PROBLEM OF THE THICKNESS OF A LAYER ENTRAINED BY A ROTATING DRUM PARTIALLY IMMERSED IN A LIQUID

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Results are presented from experimental studies of the thickness of a layer of viscous normal liquid entrained by a drum rotating at a speed greater than the boundary for the retention of shape in the static meniscus.

An estimate of the magnitude of the liquid layer entrained by rotating bodies of cylindrical shape is of great significance in studying problems relating to the application of a layer of dissolved substance onto the surfaces of bodies extracted from solutions; it is also important in the transmission of liquid lubricating materials, in the metering out of paints and adhesives in polygraphic and automatic packing machines, etc.

The problem of the slow withdrawal of a body from a nonmoving liquid has repeatedly been considered in the literature [1–8]. It has been established that the thickness of the entrained liquid layer is a function of the velocity of body motion, as well as of the viscosity, density, and surface tension of the liquid, and also of the distance of the point in question from the free surface of the liquid.

In this paper we have stated the following problems: 1) to determine the thickness of the layer entrained by a horizontal drum rotating at a speed in excess of the boundary for the retention of shape in the static meniscus; 2) to determine with greater accuracy the conditions under which the effect of surface tension ceases to make itself felt; 3) to establish the boundaries of applicability for the resulting relationships.

Characteristics of the Tested Liquids

Liquid	μ, (N · sec)/m^2	ρ, kg/m^3	σ, N/m
Transformer oil	0.0285	883.0	0.0315
33% transformer oil + 67%	0.069	884.5	0.0298
Compressor oil	0.250	896.0	0.0340
75% transformer oil + 25% compressor oil	0.038	887.0	0.0323

The work was carried out with viscous normal liquids (table) which wetted the drum surfaces very well. The viscosities of the liquids were determined by means of a capillary viscosimeter, the surface tensions were determined by a bubble-jumping method, and the density was determined with a pycnometer. Two steel-45 drums 80 and 60 mm in diameter and 100 mm long were used for the study. The thickness of the layer was measured with a micrometer screw to whose end a needle was attached. The idea behind the use of this method is not new [6]. It has been established that the boundary effect is sensed at distances to 13–14 mm from the ends of the drum, and the measurements were therefore carried out at points