EJECTORS PULSATING PROCESSES INVESTIGATION

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Abstract
A high level mathematical model for describing a gas dynamic process in a pulse ejector is presented in this paper. The model is based on non-steady 2D equations of gas dynamics with periodically changing boundary conditions at the inlet of the active duct.

The influence of such parameters as gas pressure and temperature at the inlet of the active and passive ducts, duct geometry, cycle frequency, on-off time ratio and others on the device characteristics has been studied on the base of multivariant computations. Such combinations of the parameters at which the coefficient of ejection is 10-15 times increased in comparison with the same parameters (pressure and temperature) of the stationary ejector of the same geometry have been received.

INTRODUCTION

The ejection process involving pulsations at certain mechanical and geometrical ratios of the gas dynamic flow is capable of a substantial gain in terms of mass flow and momentum of the ejected gas in comparison with the conventional steady-state process [1, 2]. This phenomenon is stipulated by the presence of spatially separated regions with predominant increase of additional mass in rarefaction waves of small energy dissipation.

The experimental investigations [1] have proven the high efficiency of the pulsating ejection process that results in a well-founded interest in this problem from the standpoint of the usage of pulsating effects in applied tasks. The pulsating mode of the active jet can be achieved by various methods (mechanical and gas dynamical) that creates a great variety of application [2].

1. A mathematical model of the gas flow in the pulse ejector.

The ejector is a duct (axisymmetrical or flat) with a random generatrix; the duct inlet section has two sources of gases of high and low pressure (fig.1).

The environment static pressure can be set at the outlet of the ejection duct.

At the pulse ejector operation the active jet enters into the duct only during some limited time t, then the section through which the active gas is being delivered is blocked and the passive gas continues to flow into the ejection duct due to rarefaction caused by the blocking of the source of the active gas. After some period of time t the section of the active gas is opened again and the high-pressure gas enters into the duct during the time t and so on.

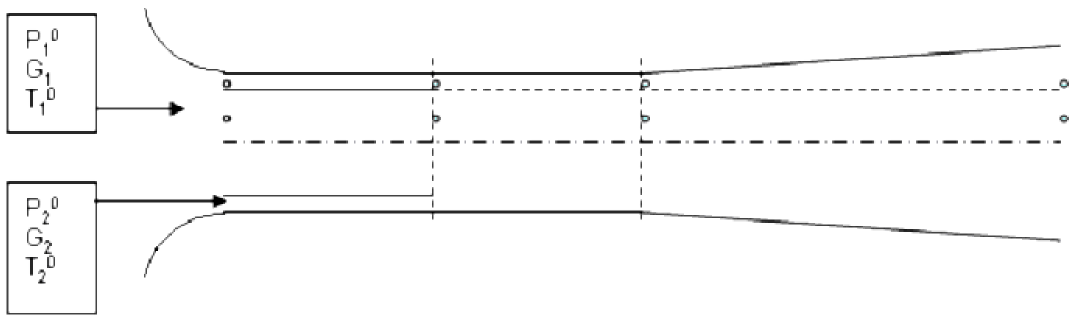

Figure 1- The meridian section of the pulse ejector axisymmetrical duct. 1-active jet, 2-passive jet

At the ejector inlet section (fig.1) the total parameters of the active and passive gas are considered to be given. The parameters of the active gas are designated by an index 1 and of the passive gas – by an index 2.

According to the above-mentioned mechanics the phenomenon of non-steady periodical gas flow in the pulse ejector duct can be simulated by the non-steady equations of gas dynamics for the non-viscous, non-heat conducting gas with periodic boundary conditions. These equations precisely describe losses of a wave character.

The equations of gas dynamics in the Cartesian coordinate system are the following:

$$\begin{aligned}
&\frac{\partial \rho}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho v}{\partial y}=f_1\\
&\frac{\partial \rho u}{\partial t}+\frac{\partial (p+\rho u^2)}{\partial x}+\frac{\partial \rho v}{\partial y}=f_2\\
&\frac{\partial \rho v}{\partial t}+\frac{\partial \rho uv}{\partial x}+\frac{\partial (p+\rho v^2)}{\partial y}=f_3\\
&\frac{\partial e}{\partial t}+\frac{\partial (e+p)u}{\partial x}+\frac{\partial (e+p)v}{\partial y}=f_4
\end{aligned} \tag{1}$$

Here U(u,v) – a vector of gas velocity with components u, v, e= $\rho\left(\varepsilon + \frac{U^2}{2}\right)$,

ε =ε (p,ρ),

where $U^2 = |U|^2 = u^2 + v^2$, ε - gas internal energy, ρ - gas density, p - pressure, x,y - Cartesian coordinates, t - time, $f = \{f_1, f_2, f_3, f_4\} = -\frac{1}{y}\{\rho v, \rho uv, \rho v^2, (e+p)v\}$ – for an axisymmetrical case, for a flat case – f=0.

A Godunov method is used as a numerical integration of the equations (1).

2. Measures of efficiency of the pulse ejector.

The following factors can be considered as measures of efficiency of the pulse ejector operation: a coefficient of ejection n = G_2/G_1, jet momentum at the outlet P3, total energy of the flow E3, kinetic energy of the flow K3 at the outlet section. The ratios of these parameters and some initial values at the ejector inlet are the coefficients that characterize the pulse ejector operation. All mentioned parameters represent time and area integrals of corresponding sections during a period of steady-state periodical mode related to the time of the cycle.

3. Parameters that govern the process in the pulse ejector.

For this task write the governing parameters in a non-dimensional form, then relate the values with dimensions of pressure to P_2^0 and the values with dimensions of temperature to T_2^0, take l as a unit of length and $t^* = l\left(\gamma R T_2^0\right)^{-1/2}$ - as a unit of time, where R-gas constant. Let us consider that the ejector duct consists of three elements (by analogy with a stationary ejector duct): an inlet L1 (up to the section x = 0, see fig.1), a cylindrical mixing chamber L2 and a conical diffuser L3 with the expansion at a given angle with the axis. The form of the active jet duct can be cylindrical of a constant diameter or tapered or represent a Laval nozzle.

This restriction in the selection of the forms of the pulse ejector duct is connected with the fact that the task of the selection of the optimal form at non-steady process has not been solved yet and is of great difficulties of both theoretical and numerical character. The element - to- element optimization of the ducts described in this paper demonstrates good results and corresponds to available experiments.

So the non-dimensional governing parameters are the following: $P = \frac{P_1^0}{P_2^0}, T = \frac{T_1^0}{T_2^0}, P_3 = \frac{p_3}{P_2^0}, \tau = \frac{T_{akt.}}{T_{cikl.}}$ - a relative fraction of time during the active jet operation, $Sh = \frac{T_{cikl.}}{t^*}$ - a Strouhal number, $l_i = \frac{L_i}{l}$ = -relative lengths of the ejector duct (i = 1, 2, 3; $\sum l_i = L$), relative radii of cross-sections of elements of the ejector duct and the active jet duct $\frac{R_i}{l_m} = H_i, \frac{r_k}{l} = h_k$ (i, k-correspond to the elements of the given ducts).

At solving concrete tasks the mentioned parameters can change within a given range or be fixed.

4. Optimization of pulse ejector characteristics.

One of the most important characteristics of efficiency of the pulse ejector is a coefficient of ejection n = G2/G1. Other integral characteristics are essentially defined by this coefficient n and increase together with it.

It is worth noting that for the pulse ejector it is important to choose an optimal value of the combination of the governing parameters. For this purpose a number of computations has been performed at which the governing parameters have been varied within the following ranges: pressure in the active jet $1{,}25 \leq P \leq 10$; temperature $1 \leq T \leq 3{,}5$; a fraction of time during the active jet operation $0{,}1 \leq \tau \leq 1$; process frequency characterized by a Strouhal number $0{,}015 \leq Sh \leq 1{,}5$.

The elements of the ejector duct have been also varied.

The computations have been performed to establish values of flow governing parameters which result in the maximum value of the relative momentum at the ejector outlet; besides variants of a momentum of the nozzle (with and without an adapter) have been compared.

The maximum value of integral characteristics has been received at the following values of the governing parameters: $\tau = 0{,}1$, relative values of process frequency Sh = 0,1134, pressure P = 1,25, temperature T = 3,5, radius of the active nozzle cross-section H = 0,3. It is worth noting that at $P \geq 6$ and $0{,}4 \leq \tau \leq 0{,}6$ the blocking of the ejector duct takes place, therefore the data for these governing parameters that do not cause this phenomenon are given below. The analysis of the computation results has shown that the momentum at the outlet of the ejector with a pulsing active jet can be 2 times more in comparison with a stationary ejector.

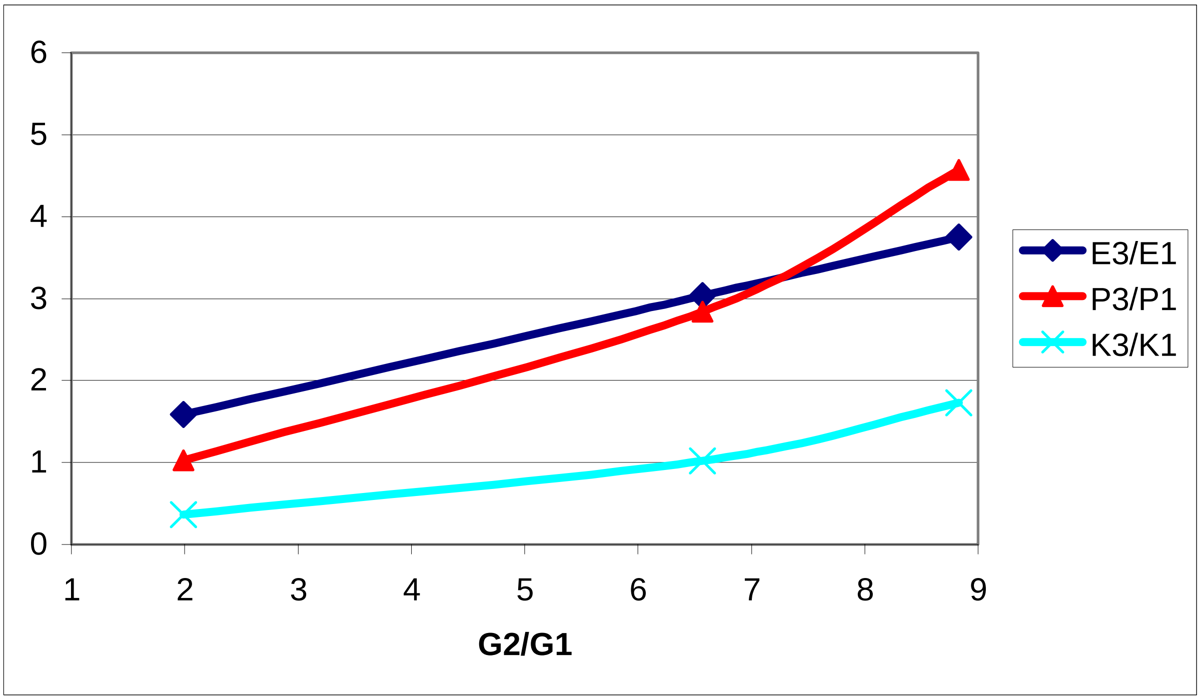

Figure 2 - The relationship of the pulse ejector integral characteristics and a coefficient of ejection.

It should be noted that at high pressure a value P has the greatest influence of integral characteristics. The influence of temperature T is insignificant. The optimization of the forms of the active gas duct and the ejector duct has shown that the tapered duct of the active gas allows to get approximately n ~ 20% increase of the coefficient of ejection n at the optimal length ~ 120 in comparison with the constant section duct. At the optimization of the form of the ejector duct the construction which has a rectilinear portion and a subsequent tapered one (see fig.1) has appeared to be the best one. In this case the coefficient n in this duct is 3,6 times greater than in the constant section ejector and 9% more than in the tapered ejector.

The values of the relationship of the momentum at the outlet section of the ejector and the momentum of the active nozzle without an ejector adapter (column 3) and the relationship of the momentum of the ejector outlet section and the momentum of the active nozzle in the ejector adapter (column 4) are given in tables. It can be seen from the table that the application of the ejector adapter at the optimal choice of parameters results in more than 2 times increase of the nozzle momentum.

Table 1 – Output integral behaviour for pulse ejector

values of governing parameters	*Sh*	*P3 with an ejector/P1 without an ejector*	*P3 with an ejector/P1 with an ejector*	*K3 with an ejector/K1 without an ejector.*	*E3 with an ejector./E1 without an ejector*
P=1,25 T=3,5 τ=0,1	*0,08*	*0,93*	*3,49*	*0,20*	*2,25*
	0,11	*1,01*	*4,57*	*0,24*	*2,19*
	0,15	*2,29*	*2,48*	*0,96*	*2,82*
	0,19	*1,34*	*1,26*	*0,42*	*2,89*
P=1,5 T=3,5 τ=0,1	*0,04*	*0,75*	*1,13*	*0,22*	*1,52*
	0,08	*0,89*	*1,99*	*0,26*	*1,99*
	0,11	*0,93*	*2,72*	*0,24*	*2,08*
	0,15	*1,68*	*2,16*	*0,74*	*2,17*
	0,19	*1,26*	*1,11*	*0,43*	*7,61*
P=8 T=1 τ=0,8	*0,45*	*2,05*	*2,05*	*3,71*	*1,13*
P=6 T=3,5 τ=0,9	*4,54*	*1,31*	*1,31*	*1,48*	*1,10*

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