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EXPERIMENTAL EVALUATION OF THE DISTRIBUTION FUNCTION OF DROPLETS IN A VISCOELASTIC LIQUID SPRAY

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Statistical processing of results is carried out for an experimental investigation of the process of atomization of a viscoelastic liquid column ejected from a circular channel by a compressed gas. The distribution function of droplets in a spray is constructed in the selected region of variation of the initial parameters.

In solving a number of problems use is made of technical facilities in which a viscoelastic liquid is ejected by means of the pressure of a compressed gas from channels of limited length. Basic propositions for a theoretical description of the process of viscoelastic liquid atomization and the construction of the size distribution function are expounded in [1]. However, the conditions for the practical realization of the process of atomization vary over a wide range. Experimental investigations within this range make it possible to specify the existing premises and to assess their adequacy for real processes.

The aim of the experimental investigations conducted was to construct the size distribution function in a spray of a viscoelastic liquid column with $L/D \in 20-40$.

In carrying out the investigations, a setup was used that incorporated a test pressure gauge, an air receiver, a solenoid-operated pneumatic valve (SPV), a device for fixing the channels investigated, a test channel, and a screen trap.

When an electric signal is supplied to the SPV, the latter opens and joins the receiver to the test channel. The capacity of the air receiver $0.5 \cdot 10^{-3}$ m^3 ensures the maintenance of a constant pressure drop between the ejection and the surrounding medium when a viscoelastic liquid column moves along the channel. The relative change in the pneumatic system volume does not exceed 0.5%; there is no throttling in the open SPV. The screen trap is installed at a distance of 2.0 m from the test channel cut.

The droplets formed upon atomization of a viscoelastic liquid column deform when they strike the screen trap. The deformed droplets remain unchanged on the surface of the screen trap. The determination of the size of droplets by their deformed traces is made in the following sequence:

1) grouping deformed droplets by characteristic dimensions and counting the numbers of them in groups;
2) selection of a control batch of droplets from each group for weighing with an analytical balance;
3) calculation of the volume of droplets by mass on the assumption that they had the shape of a sphere;
4) control of the accuracy of statistical processing by comparing the overall volume of droplets with the volume of the ejected viscoelastic liquid column.

Based on the results of statistical processing, graphs of the dependence of the number of droplets on their diameter are plotted (Fig. 1). The numbers of the graphs in the figure correspond to the numbers of the tests in which they were obtained (see Table 1). Analysis of Fig. 1 shows that the size distribution spectra of droplets in a spray are described by one function, which occupies different positions with respect to the coordinate axes, depending on the volume of the viscoelastic liquid ejected from the channel and the conditions of atomization. This allows one to assume the existence of statistical regularity in the size distribution of droplets.

Such an assumption was advanced earlier by Tresh [2], who investigated a pneumatic Newtonian fluid spray. Using his own methods of statistical thermodynamics, Tresh proposed a distribution function of the form

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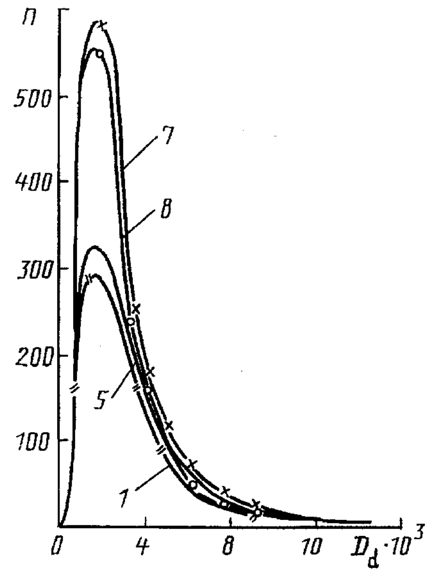

Fig. 1. Graphs of the distribution of the number of droplets n with respect to the sizes D_d (m) in a viscoelastic liquid spray.

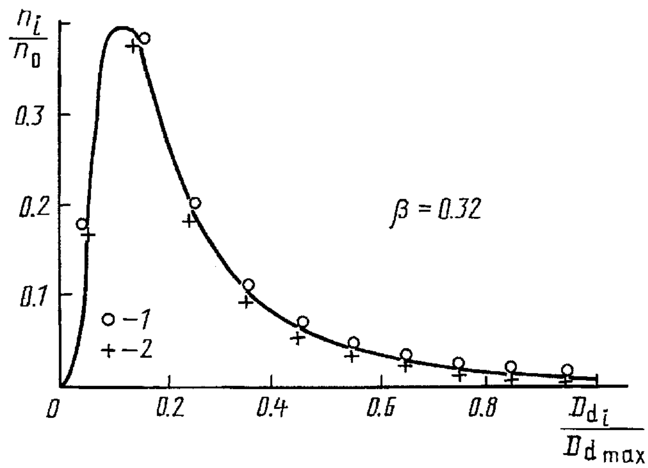

Fig.2. Generalized size distribution function of droplets in a spray of a viscoelastic liquid column. Experimental points: 1) for the conditions of the first test; 2) for the conditions of the sixth test.

$$\varphi(D_d) = \frac{dn}{n_0 dD_d} = \frac{\beta^2 D_{d_{max}}^2 \exp(-\beta D_{d_{max}}/D_d)}{D_d^3 (1+\beta)\exp(-\beta)} . \tag{1}$$

Subsequently, his ideas were developed by Golovkov, who suggested in [3] a parametrization technique for determining the magnitude of the distribution function parameter.

An analysis of size distribution functions in Newtonian fluid sprays such as those suggested by Rozin and Rommler, Nukiyama and Tanasawa, Bloch and Kichkina, and Martin et al. was made by Lyshevskii in [4]. He demonstrated that none of these functions can claim universality.

Therefore, the processing of the results was based on the assumptions developed by Tresh about the presence of statistical regularity in the size distribution function in a spray and the existence of a droplet of largest diameter in it. Tresh's distribution function was selected as the basic one and Golovkov's parametrization method was adopted for estimating the numerical value of the distribution parameter.

Table 1. Experimental Conditions and the Results of Calculation of the Distribution Function Parameter β.

No. of test					n_0	β
	Δp, MPa	$\tau_0 \cdot 10^{-3}$, Pa	$D \cdot 10^3$, m	$L \cdot 10^3$, m		
1	0.5	0.5	16	360	697	0.310
2	0.5	0.5	10	200	413	0.322
3	0.5	1.3	16	200	695	0.319
4	0.5	1.3	10	360	532	0.315
5	1.0	1.3	16	360	766	0.312
6	1.0	1.3	10	200	518	0.330
7	1.0	0.5	16	200	1124	0.327
8	1.0	0.5	10	360	974	0.325

Results of statistical processing obtained under different experimental conditions are presented in Table 1. The statistical processing has shown that the value of β is virtually independent of the experimental conditions and oscillates with a maximum scatter not exceeding 3.1% with respect to the mean value $\beta = 0.32$.

Figure 2 presents the graph of the generalized distribution density function constructed by employing Eq. (1) with $\beta = 0.32$. The graph contains points corresponding to the relative quantity of droplets within the range of grouping. The position of points along the abscissa axis corresponds to the middle of the grouping range. Comparison of the generalized density distribution function graph with the experimental distribution gives satisfactory agreement. The maximum divergence $\delta\varphi(D_d)$ does not exceed 5.2%.

The transition from relative to absolute values on the graph is made by using the values of the parameters n_0 and $D_{d_{max}}$. The value of the parameter n_0 is calculated from the condition

$$V_{col} = \int_0^{D_{d_{max}}} \frac{\pi}{6} D_d^3 n_0 \varphi(D_d)\, dD_d .$$

The relationship between the largest droplet diameter and the "mean" diameter of droplets in a spray is found experimentally. The "mean" diameter is calculated from the relation

$$\overline{D}_d = \frac{6V_{col}}{\sum_{i=1}^{n_0} S_{k_i}} .$$

The empirical relationship between $D_{d_{max}}$ and $\overline{D}_d$ (by the least-squares method) has the form

$$D_{d_{max}} = 18.8\,\overline{D}_d . \tag{2}$$

The maximum deviation of experimental points from relation (2) does not exceed 3.0%. It should be noted that the parameter $\overline{D}_d$ used for the statistical processing of experimental results corresponds to the parameter D_{20} employed for calculating the ignition conditions in a polydisperse torch of atomized Newtonian fuel fluid [5].

The introduction of the parameter $\overline{D}_d$ is explained by the need to take into account the conditions that determine the efficiency of the atomization of a viscoelastic liquid column, i.e., the channel diameter D, channel length L, limiting internal shear stress of the spatial structure τ_0, and pressure drop between the ejection and the surroundings Δp. The limiting internal shear stress of the spatial structure determines its ability to resist external influences and characterizes the "elastic" energy of a unit volume of this structure. The diameter and length of the channel as a characteristic of the volume are related to the overall energy content of the spatial structure, which prevents the decomposition of the latter. The pressure drop determines the energy spent to decompose the spatial structure of the ejected column.

The magnitudes of the above parameters, which determine the relationship between the energy content of the spatial structure of the column ejected and the gas jet energy spent to decompose this structure, govern the value of the "mean" diameter of droplets in a spray. For the range of parameters indicated in Table 1 the value of the mean diameter lies within $\overline{D}_d \in (5.27-8.33) \cdot 10^{-3}$ m. This complies with the assumption about the influence of the relationship between the "elastic" energy of the spatial structure and the destructive energy of the gas jet on the efficiency of viscoelastic liquid column atomization. This fact confirms the assumption made earlier by Sultanov and Yarin in [1] when they investigated the shock effect of electric conductor energy on viscoelastic liquid column atomization.

Based on the results obtained it is possible to state that the size distribution function in a viscoelastic liquid spray is satisfactorily described by the Tresh function with $\beta = 0.32$. However, this is valid only for a atomization function obtained within the range of the initial channel diameters $D \in (1.0-1.6) \cdot 10^{-2}$ m, channenl lengths $L \in (20.0-36.0) \cdot 10^{-2}$ m, pressure drops between the ejection and the surrounding medium $\Delta p \in (0.5-1.0)$ MPa, and limiting internal shear streses in the spatial structure of the viscoelastic liquid $\tau_0 \in (0.5-1.3) \cdot 10^3$ Pa.

The determining factor in assessing the efficiency of the atomization of a viscoelastic liquid column ejected from a circular channel by a compressed gas is the relationship between the "elastic" energy of the spatial structure and destructive energy of the gas jet, which performs ejection and atomization.

NOTATION

D_d, diameter of an arbitrary droplet in a spray; n_0, total number of droplets in a spray; dn, number of droplets between D_d and $D_d + dD_d$; $D_{d_{max}}$, diameter of largest droplet in a spray; β, distribution function parameter; V_{col}, volume of the viscoelastic liquid column; $\overline{D}_d$, "mean" diameter of droplets in a spray; $\overline{S}_{d_i}$, surface area of the i-th droplet; D, channel diameter; L, channel length; τ_0, limiting internal stress in the spatial structure of the viscoelastic fluid; Δp, pressure drop between the ejection and the surrounding medium; D_{20}, averaged diameter of droplets in a spray.

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