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THE QUESTION OF SELECTING THE DESIGNING ATOMIZERS FOR CONTEMPORARY SPRAYERS

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Zh. M. Sudit

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THE QUESTION OF SELECTING AND DESIGNING ATOMIZERS FOR CONTEMPORARY SPRAYERS

Zh. M Sudit [GSKB (State Special Design Office) for Machinery for Chemical Protection of Plants]

The introduction of low-volume treatments into chemical plant protection practice substantially increased the requirement for structures of sprayer atomizers. Treatment with highly concentrated solutions at low levels of discharge, requires the creation of a highly dispersed spray (50-100 μm) of determined quality during atomization of liquid toxic chemicals. We carried out studies of four types of high-productivity (liquid flow rate 5-50 l/min) atomizers. These devices can be used successfully on various sprayers and, in particular, on machines for treating field crops by the wind application method.

The purpose of the study was to select the optimum structure of the atomizer and to develop calculation relationships which would permit determining qualitative characteristics of the degree of dispersion of the drop cloud, quality of the designed atomizer, average drop diameter, and the law governing the size distribution of the drops.

The following atomizers were studied: No. 1 (pneumatic-disk, Fig. 1); No. 2 (pneumatic, Fig. 2); No. 4 (pneumatic with a centrifugal burner, Fig. 3); and No. 5 (pneumatic-rotary, Fig. 4).

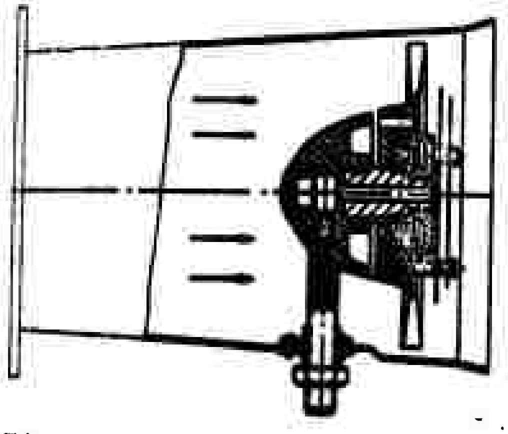

Fig. 1.

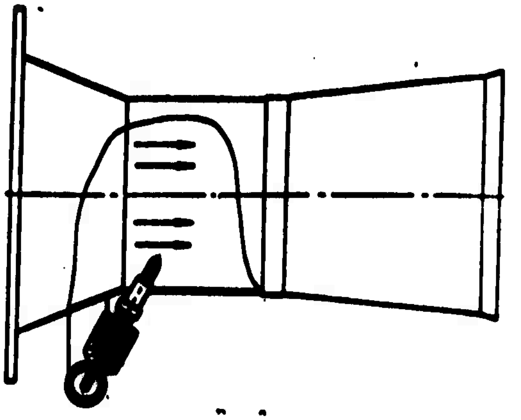

Fig. 2.

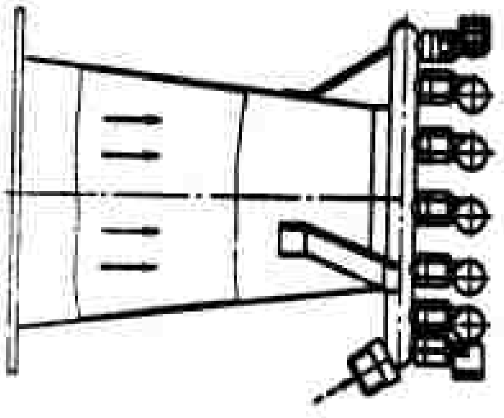

Fig. 3.

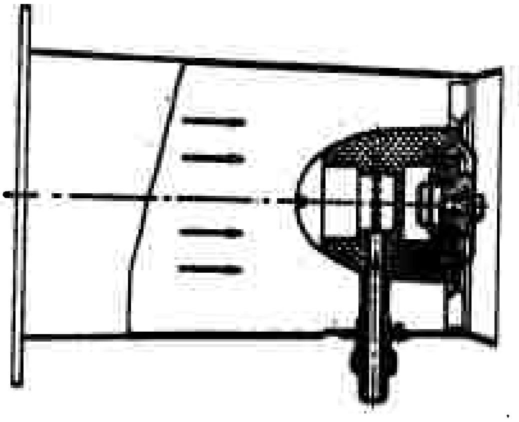

Fig. 4.

On the figures the solid arrows show the path of air and the broken arrows, the path of the liquid.

All of the atomizers selected for study differ essentially from one another [1]. The structures of the atomizers were selected by analogy with structures already in practical use.

The atomizers were designed for operation in combination with a fan, since at present blower sprayers have been found to be most useful for achieving high productivity.

The air flow in the sprayers fulfills various functions: it may break up the liquid and may also transport drops of atomized toxic liquid chemicals to the object to be treated. In certain cases the airflow may accomplish both.

In the optimum mode, when the power consumed by the fan equals ∿40 h.p. (this ensures the possibility of mating with a 1.4-ton class tractor), the dynamic head corresponds to the speed of the airflow and equals ∿100 m/s.

To determine the degree to which the airflow participates in the process of atomizing the liquid it is necessary to determine the quality of its preliminary atomization and also the possibility of a flow with the parameters indicated above.

Preliminary atomization will obviously take place during operation of atomizers No. 1, 4, and 5. However, with available relationships it is possible to calculate the degree of atomization only for atomizers No. 1 and 4.

To determine the degree of dispersion created by the disk atomizer we can use the following equation [2]:

$$d_m = \frac{2A(B+Q)}{\gamma^{1/3} c^{K/3}}, \tag{1}$$

where A and B are constants which depend on the physical properties of the liquid (for water A = 4.15 and B = 430); γ is the specific weight of the liquid; Q is the productivity of the disk in kg/h; $c = R\omega^2$ is the centrifugal acceleration developed by the disk in m/s^2; and K is a constant (for water K = 1).

In our case, with n = 11,000 r/min and two disks 150 mm in diameter, d_m = 500 μm even with a minimum liquid flow rate of 5 l/min.

Obviously, with an increase in the flow rate of the liquid the value of d_m will also be increased.

To determine the degree of dispersion created by the centrifugal atomizer we will use an empirical equation with N. Strulevich's coefficients:

$$\frac{d_m}{d_c} = \frac{\left(\frac{\sigma_ж}{\sigma_0}\right)^n + \left(\frac{\gamma_ж}{\gamma_0}\right)^m}{AM^{0.817}\sqrt[3]{\frac{P}{760}}}\mu\varphi, \qquad (2)$$

where d_c is the diameter of the atomizer nozzle; $\mu\phi$ is the flow rate coefficient; σ_0 and γ_0 are the surface tension and dynamic viscosity of the base liquid (kerosene); M is the Mach number; P is the pressure in the medium; $n = 0.77$; $m = 0.44$; and $A = 41.5$ (the latter are empirical coefficients).

In order to determine the atomizing capacity of the air flow we can calculate the maximum drop size in the jet by means of the equation

$$d_{np} = \frac{\sigma D}{\rho v^2}, \qquad (3)$$

where D is the atomization criterion; v is the speed of the air flow; σ is surface tension of the liquid; and ρ is the density of air.

The dimensionless atomization criterion D was determined experimentally [3, 4, 5]. Various values were obtained: Prandtl - 7.5, Volynskiy - 12-14, Bukhman - 3.5, etc. If we take the value of this criterion as 3.5 (this is one which many authors consider the most reliable), then for our experiments we obtain

$$d_{np} = 20 - 25 \ \mu m.$$

The given calculations attest to the fact that the air flow has a dominant role in the process of atomization of a liquid by the combination atomizers investigated. This assumption was borne in mind during treatment of the research results which, as will be shown below, confirmed it.

The degree of dispersion was studied on a special stand by trapping drops of an atomized liquid in a wind tunnel on a surface covered with successive layers of soot and magnesium oxide. Procedural questions are outlined in detail in works [6, 7].

As is known, the degree of dispersion created by an atomizer can be characterized through two parameters: some average size of the drops and the distribution function for the totality of drops with regard to size.

As the average drop sizes we took the diameter d_m, mass median, and the average diameter per Sauter, d_s.

As is well known, d_m is determined as the drop diameter which divides the entire volume of the atomized jet into two equal parts - i.e., into the total volumes of drops

$$\sum_{i=1}^{m} n_i d_i^3 = \sum_{i=m+1}^{n} n_i d_i^3, \tag{4}$$

whose dimensions are greater or lesser than d_m, while d_s corresponds to the drop for which the ratio of volume to surface equals the ratio of total volume of all drops to the sum of their surfaces:

$$d_s = \frac{\sum n_i d_i^3}{\sum n_i d_i^2}, \tag{5}$$

where n_i is the number of drops with diameter d_i.

The drop size distribution function for our case should be described by the empirical formula [8]

$$l_n R_i = -0,69 \left(\frac{d_i}{d_m}\right)^m. \tag{6}$$

where R_i is the weight fraction of the fluid consisting of drops whose dimensions are greater than d_i; m is an empirical coefficient.

The results of the experiment were processed by mathematical statistics methods. Dispersion analysis - comparison of the sample averages and dispersions - demonstrated the minor nature of the difference between the quality of operation of the investigated atomizers and the studied ring of process parameters.

This allows us to conclude that the form and quality of preliminary atomization does not have an essential influence on the final dispersion in the studied range of process parameters. Such a conclusion is extremely important from the practical point of view, since it allows us to approach the selection of the atomizer by evaluating only its operational and structural qualities.

Thus, for example, in our case preference should be given to atomizer No. 2, since it is extremely simple in structure and has no rotating parts or narrow sections to get plugged up during operation.

Besides this, it was found that at volume flow rate ratios for air and liquid greater than 5500 - i.e., with fluid flow rates which in our case do not exceed ∿15 l/min - the average drop size does not essentially depend on liquid flow rate (Fig. 5). This conclusion is of practical importance. It frequently happens duri spraying that for agricultural engineering considerations the average drop size of the liquid must be maintained constant while the rate of discharge per hectare must be changed.

Our conclusion makes it possible to accomplish this without changing the optimum travel speed of the unit during treatment.

In the last 40-50 years numerous attempts have been made to provide a theoretical substantiation for the process of atomization of a liquid.

However, the results obtained in this area do not permit direct transition to engineering calculations. Many investigators therefore turn to semi-empirical and empirical relationships, and in particular to the formula developed by Nukijama and Tanasawa [9]:

$$d_s = \frac{585\sqrt{\sigma}}{v_0\sqrt{\rho_ж}} + 597\left(\frac{\mu_ж}{\sqrt{\rho_ж \sigma}}\right)^{0.45}\left(\frac{1000 v_ж}{v_в}\right)^{1.5}, \qquad (7)$$

where d_s is the average diameter per Sauter; v_0 is the relative velocity in the constricted cross section; $\rho_ж$, $\mu_ж$, and σ are the density, viscosity, and surface tension of the liquid; $v_ж$ and $v_в$ are the volume flow rates of the liquid and air, respectively.

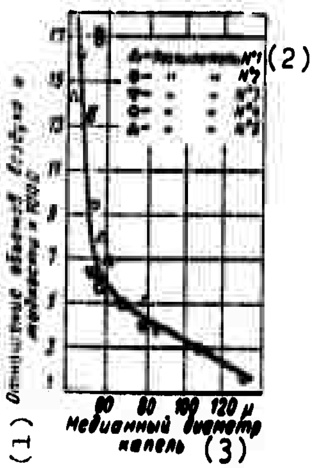

Fig. 5.
KEY: (1) Ratio of volumes of air and liquid, ×1000; (2) Atomizer; (3) Median diameter of drops.

The table gives experimentally determined diameters and those calculated by formula (7) for atomizers No. 2 and 4. It is not hard to note that a definite relationship exists between them. Statistical processing of the results showed that formula (7) gives a satisfactory description of the general nature of the dependence of average diameter on process parameters.

However, it does not give reliable results for the case of atomization of a liquid by high-productivity industrial atomizers; this is evidently because it was obtained on the basis of processing data from experiments with miniaturized laboratory nozzles.

№ опыта (1)	Соотношение $v_в/v_ж$ (2)	d'_s	d_s по уравнению Нукиямы-Танасавы (3)	d'_s/d_s	№ опыта (1)	Соотношение $v_в/v_ж$ (2)	d'_s	d_s по уравнению Нукиямы-Танасавы (3)	d'_s/d_s
1	17 800	59,24	34,41	1,72	10	2 860	101,20	45,45	2,23
2	16 700	57,19	34,43	1,66	11	1 690	120,79	52,4	2,31
3	13 300	52,86	34,32	1,54	12	1 700	107,72	51,6	2,13
4	13 800	53,07	34,32	1,55	13	16 800	59,22	32,726	1,81
5	6 200	55,99	39,19	1,43	14	16 800	52,012	32,726	1,59
6	6 200	57,39	39,19	1,46	15	8 850	52,553	31,256	1,68
7	4 050	81,15	43,65	1,81	16	8 500	50,296	31,4	1,60
8	4 050	67,41	43,65	1,54	17	5 600	52,64	34,19	1,54
9	3 180	98,75	44,87	2,21	18	5 700	52,16	33,06	1,58

KEY: (1) No. experiment; (2) Ratio $v_в/v_ж$; (3) d_s from Nukijama-Tanasawa formula.

For this case we can recommend that the following factors be introduced into the Nukijama-Tanasawa formula:

$$\left.\begin{aligned} d'_s &= d_s \cdot 1{,}6 \text{ for } v_в/v_ж > 5500; \\ d'_s &= d_s \cdot 2{,}2 \text{ for } v_в/v_ж < 5500. \end{aligned}\right\} \quad (8)$$

The increase in the factor when the boundary $v_в/v_ж \approx 5500$ is crossed is explained by the fact that the second term in the Nukijama-Tanasawa formula probably gives an insufficiently accurate reflection of the process of coagulation during atomization of a liquid by our atomizers.

Actual distributions of drops in terms of size were presented in the form of the empirical formula (6).

Statistical treatment of the empirical values of the exponent m showed that the average value can be taken as equalling 2.

Dispersion analysis confirmed the insignificant differences between the most widely divergent distributions and the curve.

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