Influence of the droplet size on the uniformity of the distribution of protective material over the surface of agricultural machinery

A I Ushanev¹, I A Uspenskiy¹, I A Yukhin¹, O V Filyushin² and A V Podyablonskiy²

¹Ryazan State Agrotechnological University named after P A Kostychev, 1, Kostycheva str., Ryazan, 390044, Russia
²Academy of Law and Administration of the Federal Penal Enforcement Service, 1, Sennaya str., Ryazan, 390000, Russia

E-mail: aushaniev@inbox.ru

Abstract. A decrease in the diameter of a droplet of a protective coating stream occurs in cases of a decrease in the diameter of the nozzle, an increase in the volumetric flow rate and the lower surface tension coefficient. To study the effect of droplet sizes on the quality of the protective coating, the conditions for obtaining droplets of different diameters were determined. During the experiment, it was found that the most significant parameters were those of the nozzle and the operating pressure of the installation. The change of these parameters caused the change of the size of the material droplets. To do this, replaceable nozzles with various diameters were installed and the supply pressure was also regulated.

1. Introduction
To store agricultural machinery, high-quality protective materials and appropriate equipment parameters are necessary. Ignorance of parameters of the installation for a protective coating on the surface of agricultural machinery can reduce its protective performance and cause the equipment failure.

2. Theoretical studies of the application and distribution of a protective coating on the surface of an object
The application of a protective coating on prepared surfaces depends on size and speed of droplets and the uniformity of the flow. It has been theoretically established that uniform coating is influenced by a decrease in the droplet of the protective material flow [1-3]:

\[ D = \frac{12\sigma}{\rho_\eta \pi^{\frac{1}{4}} - \rho_g \gamma_1^{\frac{1}{4}}} \]

A decrease in the diameter of a droplet of a protective coating stream occurs when:
- reducing the diameter of the nozzle (Figure 1),
- increasing the volumetric flow (Figure 2),
- reducing the surface tension coefficient (Figure 3).
Figure 1. The dependence of the change in the diameter of the droplet on the nozzle diameter. $\Delta d$ is the interval for changing the nozzle diameter of spray guns, recommended by manufacturers for hydraulic application.

Figure 2. The dependence of the droplet diameter on the volumetric flow rate. $\Delta Q$ is the average flow rate range obtained with standard hydraulic units.
The dependence of the change in the diameter of the droplet on the coefficient of surface tension. $\Delta \sigma$ is the selected range of changes in the surface tension coefficient of protective coatings (primer GF-21 with a solvent up to 15\%).

Theoretically, the effect of the GF-21 primer droplet formation on the uniformity of the protective coating has been established. The rational diameter of the droplet can be considered a value in the range from 30 to 38 microns [4–6].

3. Experimental studies of the application of protective coatings on the surface of agricultural machinery

To study the effect of droplet sizes on the quality of the protective coating, the conditions for obtaining droplets of different diameters were determined. During the experiment, it was found that the most significant parameters were those of the nozzle and the operating pressure of the installation. The change of these parameters caused the change of the material droplets size. To do this, replaceable nozzles with various diameters were used, and the supply pressure was also regulated. The material was sprayed onto glass slides [7, 8]. To determine the average droplet size, an ALTAMI microscope was used (Figure 4).
The size of the droplet is usually understood as its diameter, which can characterize only flying droplets with a spherical shape. In the simplest case, when all three linear sizes can be measured (Figure 5): length $l$, width $b$ and height $h$, the equivalent diameter $D$ is calculated (2) as the arithmetic mean of them:

$$\bar{D} = \frac{(l+b+h)}{3}$$  \hspace{1cm} (2)

![Figure 5. Basic linear particle sizes.](image)

In numerical terms, the shape of particles is usually characterized using various coefficients, taking into account the degree of irregularity of the shape.

The average particle diameter of the system or its fraction is often used as one of the characteristics of a polydisperse system. It is the average diameter that is used to evaluate the specific surface of particles, as well as when calculating parameters of technological processes and equipment [9, 10].

To determine the size of droplets, an image recognition program, developed at FSBEI HE RSATU, was used. To average the droplet size, the number-average diameter $\bar{D}_n(3)$ was used, which corresponded to the diameter of droplets of the monodisperse system, while the number of droplets had the same sum of diameters as in this dispersed system (Figure 6):

$$\bar{D}_n = \frac{\sum_i d_i n_i}{\sum_i n_i}$$  \hspace{1cm} (3)

where $n_i$ is the number of droplets in the i-th fraction (diameter of $d_i$); $\sum_i n_i$ is the total number of droplets in the system.
Figure 6. General view of droplets on the treated surface when recognizing their diameter

The standard deviation was determined on the basis of the same initial data as the number-average droplet size. The standard deviation for our case was calculated using the following formula (4):

$$\delta = \sqrt{\frac{\sum n_i (d_i - \bar{d}_n)^2}{\sum n_i}}.$$  \hspace{1cm} (4)

To evaluate the uniformity of droplets of the dispersed system, the coefficient of variation was used (5):

$$K_n = \frac{\delta}{\bar{d}_n} \times 100\%$$ \hspace{1cm} (5)

where $\delta$ is standard deviation, which characterizes the range of distribution of particles according to sizes. Typically, a system is considered to be monodisperse, if the coefficient of variation is less than 10 %. Specially prepared plates were treated with droplets of a fixed diameter. To determine the average thickness of the layer and its uniformity, a ET-14 brand thickness gauge was used. The results of the experiment to study the effect of the droplet size on the thickness of the primer layer and the uniformity of its application are presented in Table 1.

Table 1. The results of an experiment to study the effect of the droplet size on the thickness of the primer layer and the uniformity of its application

| #  | The average droplet size, microns | The average thickness of the layer, microns | Change of the layer thickness $\theta$, % |
|----|---------------------------------|--------------------------------------------|----------------------------------------|
| 1  | 26.1                            | 16.4                                       | 4.15                                   |
| 2  | 32.3                            | 17.8                                       | 3.66                                   |
| 3  | 35.8                            | 20.0                                       | 3.54                                   |
| 4  | 41.1                            | 24.0                                       | 3.89                                   |
| 5  | 45.7                            | 29.9                                       | 6.71                                   |
| 6  | 51.2                            | 42.1                                       | 11.27                                  |

To analyze the uniformity of the distribution of the primer material over the surface of the sample, the coefficient of variation was calculated from the effect of the droplet size on the primer layer. Based on the data obtained (Table 1), a graph was constructed (Figure 7).
Figure 7. The dependence of the coefficient of variation on the diameter of the droplet according to the influence of the size of droplets on the thickness of the primer layer

4. Conclusion
1. The effect of the protective coating droplet formation for the uniform protective coating has been theoretically established.
   2. A droplet in the range from 30 to 38 microns can be considered the rational diameter.

References
[1] Anuryev S G, Kiselev I A, Ushanev A I, Malyugin S G and Popov A S, RUS Patent No. 160193 Gun-sprayer (10 March 2016)
[2] Byshov N V, Yukhin I A and Ushanev A I 2017 Development of nozzles for applying preservation material at constant pressure Herald of Ryazan State Agrotechnological University named after P. A. Kostychev 3(35) 88–91
[3] Vigdorovich V I, Shel N V, Tsygankova L E, Tanygina E D, Esina M N and Uryadnikov A A 2018 Universalism of hydrogen sulfide and carbon dioxide corrosion inhibitors in conditions of oil production and processing Chemical and Petroleum Engineering 54(3–4) 202–210 DOI: 10.1007/s10556-018-0464-5.
[4] Vigdorovich V I, Tsygankova L E, Shel N V, Knyazeva L G, Dorokhov A V and Uryadnikov A A 2018 Protection of carbon steel against atmospheric corrosion by volatile inhibitors of IFKhAN series at high concentrations of CO2, H2S and NH3 Int. J. of corrosion and scale inhibition 7(2) 175–184 DOI: 10.17675/2305-6894-2018-7-2-5.
[5] Vigdorovich V I, Tsygankova L E, Dorohova A N, Dorohov A V, Knyazeva L G and Uryadnikov A A 2018 Protective ability of volatile inhibitors of IFKhAN series in atmospheric corrosion of brass and copper at high concentrations of CO2, NH3 and H2S in air Int. J. of Corrosion and Scale Inhibition 7(3) 331–339 DOI: 10.17675/2305-6894-2018-7-3-4
[6] Tsygankova L E, Kostyakova A A, Alshikha N and Vigdorovich V I 2018 Corrosion of steel in weakly acidic media at low H2S concentrations Int. J. of Corrosion and Scale Inhibition 7(1) 102–111 DOI: 10.17675/2305-6894-2018-7-1-9.
[7] Tsygankova L E, Vigdorovich V I, Knyazeva L G, Dorokhov A V, Dorokhova A N and Vigedorowitsch M V 2019 Suppression of local corrosion of steel, brass and copper with IFKhAN-114 volatile inhibitor Int. J. of Corrosion and Scale Inhibition 8(1) 42–49 DOI: 10.17675/2305-6894-2019-8-1-4.
[8] Vigdorovich V I, Tsygankova L E, Shel N V, Golovchenko A O, Ostrikov V V and Vigdorowitsch M V 2019 Using data of weight tests and impedance spectroscopy to evaluate the protective effectiveness of zinc-rich oil coatings in corrosion of carbon steel *Int. J. of Corrosion and Scale Inhibition* **8**(2) 212–224 DOI: 10.17675/2305-6894-2019-8-2-4.

[9] Vigdorovich V I, Vigdorowitsch M V, Tsygankova L E, Uryadnikova M N and Shel N V 2019 A lean method for determination of dynamic capacity of a sorbent at multiple sorption of cations *Int. J. of Environmental Science and Technology* **16**(10) 6227–6236 DOI: 10.1007/s13762-019-02332-4.

[10] Vigdorovich V I, Tsygankova L E, Knyazeva L G, Shel N V, Dorokhova A N and Vigdorowitsch M V 2019 Evaluation of the protective efficiency of IFKhAN-114 volatile inhibitor against atmospheric corrosion of copper by polarization measurements *Polymer Science. Series D* **12**(2) 162–166 DOI: 10.1134/S1995421219020254.

[11] Byshov N V, Borychev S N, Uspensky I A, Yukhin I A, Golikov A A and Filyushin O V 2019 *IOP Conf. Series: Earth and Environmental Science* **341** 012145 doi:10.1088/1755-1315/341/1/012145